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Technical Report 519

MEASURING AND ENHANCING THE CONTRIBUTION OF HUMAN FACTORS IN MILITARY SYSTEM DEVELOPMENT: CASE STUDIES OF THE APPLICATION OF IMPACT ASSESSMENT METHODOLOGIES

Charles R. Sawyer, Marco Fiorello, Jerry S. Kidd, and Harold E. Price
BioTechnology, Inc.

Prepared for
DOD Human Factors Engineering (HFE)
Technical Advisory Group (TAG)

HUMAN FACTORS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

OTHER SUPPORTING ORGANIZATIONS

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Two earlier documents, ARI-TR-476 and ARI-RN-80-23, present the background and rationale for the present effort.

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This document reports: (a) the feasibility of an impact assessment methodology for measuring the value (cost-benefits) of human factors R&D in system acquisition, and (b) the outline of a human factors impact handbook for the systems developer. Three basic interrelated steps were involved in this effort. First, two case studies, a maneuver control system and the F/A-18, were selected, and a detailed plan for application of the

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impact methodology was developed. Next, human factors-related elements (e.g., tradeoffs, deficiencies, costs, etc.) were examined; then the impact analysis was applied to demonstrate its utility in evaluating selected design options which bear upon operator performance and compatibility issues. This exercise indicated that the impact methodology is a feasible tool for assessing the value of human factors in systems development. Finally, a human factors impact handbook for systems developers was outlined, based upon the rationale, methodology, and findings of the overall effort.

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Systems Requirements and Operations

ARI Research Reports and Technical Reports are intended for sponsors of R&D tasks and for other research and military agencies. Any findings ready for implementation at the time of publication are presented in the last part of the Brief. Upon completion of a major phase of the task, formal recommendations for official action normally are conveyed to appropriate military agencies by briefing or Disposition Form.

FOREWORD

The Human Factors Technical Area of the Army Research Institute (ARI) is concerned with human resource demands of increasingly complex battlefield systems used to acquire, transmit, process, disseminate and utilize information. This increased complexity places great demands on the operator interacting with the system. Research in this area focuses on human performance problems related to interactions within command and control centers as well as issues of system development. The research program includes both technology base and advanced development research as well as a limited amount of technical advisory service (TAS) to Army agencies and activities.

One area of special interest involves the development of estimates for the contributions of human factors in military system development. The inquiry into this topic resulted from a tri-service committee decision to investigate the possibility of providing system designers/managers with evidence of the value of human factors to compare with other pertinent information from engineers, operations research analysts and system analysts. This final report applies the impact assessment methodology of a previous report (TR 476) to two military systems to demonstrate the methodology's feasibility.

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MEASURING AND ENHANCING THE CONTRIBUTION OF HUMAN FACTORS IN MILITARY SYSTEM DEVELOPMENT: CASE STUDIES OF THE APPLICATION OF IMPACT ASSESSMENT METHODOLOGIES

BRIEF

Requirement:

To demonstrate the applicability of the recommended conceptual methodology for assessing the contribution of human factors in military system development. Also, to outline the contents of a human factors impact assessment handbook.

Procedure:

Fulfilling the requirement was a three-step process:

- First, impact analysis was selected as the appropriate methodology; two case studies, a generic maneuver control system and the F/A-18, were then selected for demonstrating the methodology. The steps in the methodology were presented, and questions related to metrics, impact areas, and available case-system documentation were addressed. A plan for implementing the methodology emerged from this effort.

- The plan for demonstrating the feasibility of impact analysis was carried out. From available documentation, human factors products were assembled for the case systems, and information about tradeoffs, system requirements, costs, decisions, constraints, and design deficiencies were derived. The human factors issue selected for the F/A-18 was foot clearance during ejection; in the maneuver control case, the issue selected was the question of the dedicated versus

non-dedicated (console) user/operator. Impact analysis was conducted to assess the cost-benefits of different design options in the two cases.

- The rationale, information, and conclusions of the project to this point served as the basis for a handbook outline. The handbook will be intended for the systems development community and will illustrate the importance of both utilizing and evaluating human factors during systems acquisition.

Product:

The results of the case studies indicate that impact analysis is a feasible method of assessing the cost-benefits of human factors in systems development. Conclusions were also reached in regard to the role of the human factors practitioner, the documentation of human factors products, and the administrative aspects of human factors in the systems context.

Utilization:

The demonstration of the methodology illustrates that there is a tool available both for presenting the contributions of human factors in a tangible form and for helping to make allocational decisions and tradeoffs which involve human performance and compatibility issues. The conceptual basis and applicability of the methodology will contribute to the handbook which is to be developed. Also, issues raised, and insights achieved, during the course of the project will contribute to that undertaking.

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CONTENTS (Continued)

CONTENTS (Continued)

EXHIBITS

CHAPTER 1
INTRODUCTION

This report represents the second phase of a multiphase project intended to demonstrate both clearly and precisely the contributions of human factors to the development of military systems. The problem is an evolutionary one in the sense that the growing sophistication of our technology, along with policy-level incentives for the immediate application of that sophisticated technology to military systems, has outstripped our capabilities for ensuring the incorporation of human factors in the design of these systems. This gap has occurred in spite of a re-growth of recognition of the problem on the part of weapons system development specialists both within and outside the official establishment. Although Department of Defense (DOD) Directives 5000.1, 5000.2, and 5000.3 specify a requirement for human factors input during each of the successive phases of the system acquisition cycle, human factors (HF) considerations often are delayed until after the basic configuration of the system has been fixed. At that point, human factors can address only the subsidiary questions of task sequences, manning level, training requirements, interfaces, etc.; the HF staff is not able at that stage to contribute to the assessment of broader conceptual issues, which should be addressed at the very beginning of the development process. Consequently, the staff is often confronted with human factors problems that might not have existed in the first place had their expertise been employed at the initial planning stage.

A contributing problem has been the lack of a methodology for evaluating objectively the contributions of human factors at <u>any</u> stage of system development. This problem of assessing human factors contributions is central to the direction and final objectives of the present effort.

Initial Project Goals

The allocation of resources for any particular endeavor within the systems development context rests upon the premise that such an endeavor has previously made a measurable contribution to the development of a system. In this regard, the importance of objective, quantifiable data for decision-making in the development process is apparent to anyone involved. The use of formal mathematical models or their near equivalent has permeated every level of system development from the engineering draftsman to the top level of the DOD. The basic philosophy is that every decision carries with it quantifiable costs and benefits which must be weighed against those of alternative decisions. There are many different cost/benefit models, but they all employ the same fundamental logical structure: Given specific system goals, alternative solutions to system-related problems must be thoroughly evaluated for their relative and/or absolute impacts upon the objectives required to meet those goals. Depending upon the nature of both the system and the problem to be resolved, such impacts can be quantified with varying degrees of ease or difficulty; the assumptions made and the methodology used depend to a large extent upon the difficulties encountered in deriving numerical impact data. Of several alternative solutions, the preferred one is, of course, the one that is predicted to most closely meet the criteria established for a successful system at the lowest cost. The reliability of quantitative impact data is therefore a crucial factor in the decision-making process.

Cost/benefit analyses have been employed in various systems-related areas, such as logistics, ordnance engineering, and equipment reliability. These areas all permit the derivation of "hard" data which can be transformed into probabilistic impacts, and for this reason such applications of cost/benefit analyses

have a high degree of acceptability. The primary purpose of the present effort has been to attain this same acceptance for human engineering solutions to systems problems via the demonstrated application of cost/benefit analysis to human factors outputs. Case studies were constructed around selected episodes in specific military systems programs. The implementation of the case studies provides the groundwork for handbooks intended to sensitize system designers to human factors issues, and human factors specialists to the needs of system designers.

Progress of the Ongoing Project

Phase I

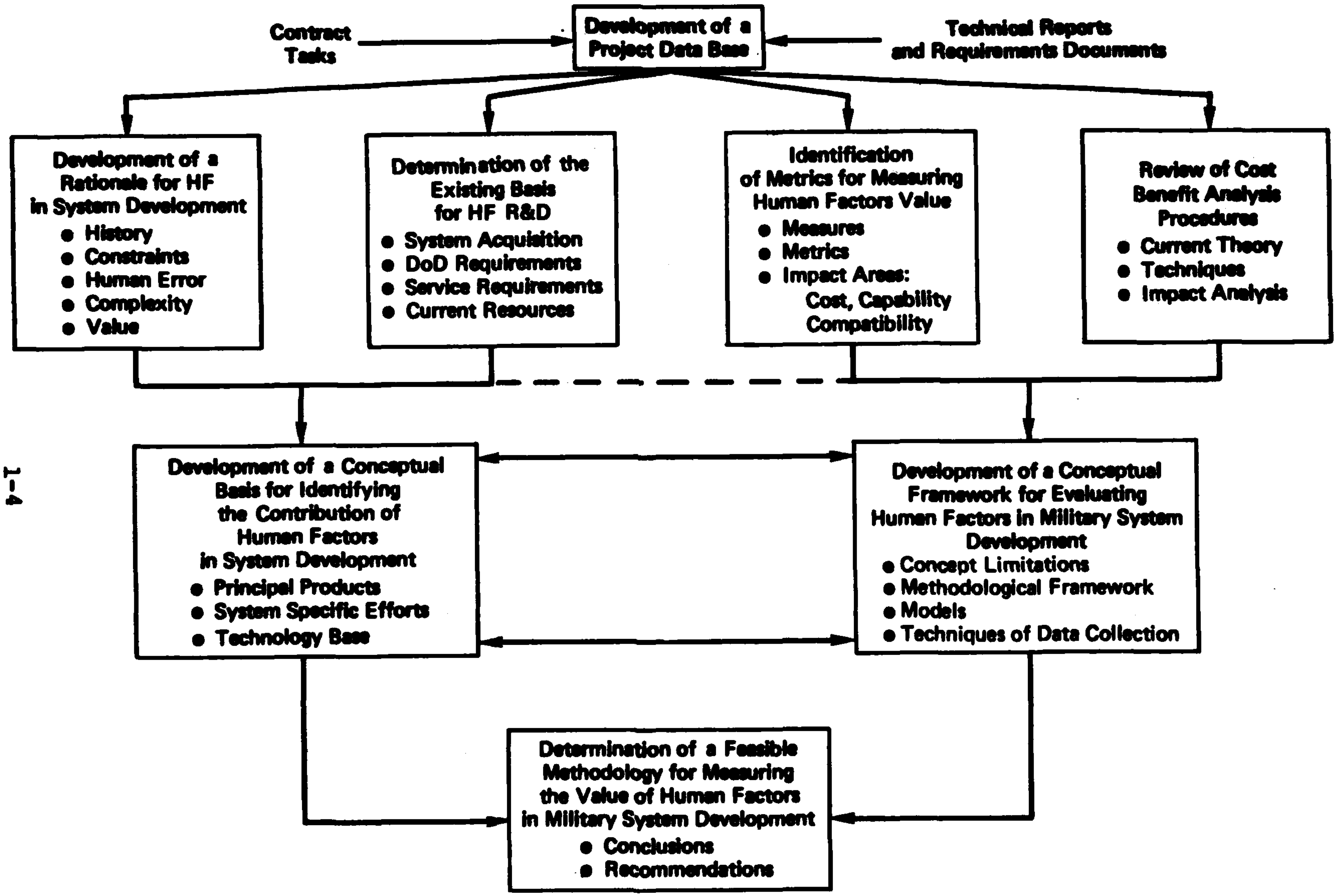
Phase I of this study (see Price et al., 1980) led to a determination of (1) a conceptual basis for human factors contributions to military systems development, and (2) a feasible method for evaluating the contribution of human factors (see Exhibit 1-1). This phase explored the HF process, examples of HF contributions and problems, the systems acquisition cycle, and cost analytic methods having potential applicability for assessing HF contributions to military systems. Out of this phase emerged two concepts of particular importance:

- The Principal Human Factors Product
- Impact Analysis.

The principal product is the cumulative outcome of the human factors process. Each stage of the development cycle yields its own, unique product. Since the effects of HF actions are cumulative, the principal product of one stage is only as valuable as those that were achieved in the preceding stages. In general, it can be assumed that the principal product *is* the contribution of human factors to the system.

Exhibit 1-1

RELATIONSHIP OF THE MAJOR EFFORTS OF THE STUDY



The assessment of HF decisions/allocations integral to a product, as against alternative decisions/allocations, leads to the second concept, impact analysis. Impact analysis is the methodology developed as the analytical tool for measuring the cost/benefits of human factors actions, assessing such actions in terms of three impact areas: cost, capability, and compatibility. The concept of impact analysis, along with the concept of the principal product, provided the thrust for the next phase of the study.

Phase II

This phase consisted of a demonstration of the cost/benefit methodology and was constructed around the principal product concept and impact analysis. This was a two-step process consisting of (1) an elaboration of the impact assessment methodology, and (2) a demonstration of the methodology using two case study systems. The case studies involved, first, the derivation of tentative principal products for a selected development stage of each of the two case systems, and then the application of the methodology to the assessment of alternative human factors actions. The case studies are presented in Appendix A.

Changing Perspectives and Revised Goals

Much of the major effort in the conduct of Phase II was devoted to the examination of documents for the purpose of extracting human factors information related to the two case systems. The difficulties encountered and findings obtained from this task led to important conclusions which bear upon the goals of the project; they are as follows:

- Few if any real systems are being developed in accordance with the formal sequence prescribed by the Secretary of Defense.
- The critical events in the systems development process are not the formalized milestones, but rather the formation of the MENS team, the appointment of the PM, and the selection of a prime contractor.
- The key events often do not reflect the participation of human factors specialists.
- A clear picture of the human factors principal product does not emerge from systems documentation. Thus, the accountability for, and contributions from, key HF decisions are elusive.

These conclusions have implications for both the concepts of the ongoing project and the target audiences of the proposed handbook. In respect to the first, the principal product should be thought of not only as the net HF contribution for any stage of systems development but also as the documentation process necessary for exhibiting such a contribution. Also, the principal products must be sufficiently flexible in content that they can be adapted to the real-world deviations from the idealized acquisition cycle. With respect to the target audience for the handbook, three parties in particular should receive attention: the combat developer, the HF staff, and the PM and his staff. The combat developer needs to be acquainted with the crucial HF issues which should be addressed during the Mission Analysis Phase. The HF staff should be aware of the importance of documenting the HF process in order to establish credibility; the staff must also be made aware of the need to assert itself to support the PM and lend assistance to the combat developer. Finally, the PM needs to be aware of both the importance of HF considerations and the resources which the HF staff has at its disposal.

Chapter 2 reviews the conceptual basis of HF contributions in more detail, focusing on the following: examples of systems HF deficiencies and utilization; the military systems procurement cycle; and the principal product concept. Chapter 3 reviews the cost/benefit approach employed. Chapter 4 presents conclusions and recommendations regarding the utilization of the cost/benefit methodology and the role of the human factors practitioner. In general, care has been taken to reflect conceptual changes occurring during the course of the project. Finally, Appendices A and B contain, respectively, the case studies and an outline of the handbooks proposed for the next project phase.

CHAPTER 2
REVIEW OF THE CONCEPTUAL BASIS FOR HUMAN FACTORS CONTRIBUTIONS

The first step in assessing the contributions of human factors to military systems was a discussion of the rationale for human factors utilization; some examples of system failures due to inadequate HF were central to this discussion. This review was followed by a formal chronology of the weapon system procurement cycle and related human factors efforts, a discussion of the principal product concept, and the conceptualization of the impact analysis framework. The present chapter presents a digest of these areas with the exception of the impact analysis framework, which is Chapter 3. The final chapter (Chapter 4) makes recommendations based upon conclusions reached during the conduct of this project.

HF Problems and Applications

With few possible exceptions, it would be unfair to label most systems as "failures" or "successes" *entirely* on the basis of the degree to which HF has been applied during systems development. However, it is fair to say that the value of HF to the success of a system is disproportionately greater than the resources usually allotted to this activity. Some systems operate poorly because of a lack of HF considerations; others appear to be successful in large part because they were designed with the human operator or maintainer in mind. Thus, it will be instructive to briefly discuss some specific systems and design decisions in which either attention or inattention to HF has had a substantial bearing upon performance.

Examples of HF Neglect and Success

Although many modern-day systems are both huge and extremely complex, difficulties related to poor human factors are encountered in even those systems which appear to be relatively simple. A recent article by Fallows (1981a) points out that the Dragon, a hand-held missile-launcher employed against tanks at short range, has limited utility because its operation conflicts markedly with basic battle-field requirements. The operator must guide the missile toward the target over a period of seconds while standing exposed on the battlefield. Not only is he himself a target during this period, but he has the additional problem of maintaining a heavy weapon on his shoulder without moving the sight following a heavy blast. This requires a rare combination of strength and skill. Similar problems exist with the TOW, a long-range missile launcher also operated by a single person. Fallows (1981b) has discussed design problems in more conventional small arms as well. For example, the M16 was fitted with an additional bolt handle which increased the tendency of soldiers to attempt the seating of jammed cartridges, behavior that leads to more severe jamming and can damage the weapon.

Given that design features of small systems can adversely affect their operation by increasing the probability of human error, the potential influence of inadequate HF upon the performance of operators in increasingly large and complex systems is understandably great. A dramatic case in point is presented in Exhibits 2-1 and 2-2. These exhibits are from recent briefings on the human factors program at the Naval Air Development Center. Exhibit 2-1 indicates the dual problem of increasing information requirements for aircraft operators and the decreasing amount of cockpit space available for providing displays or controls. As may be seen, the last (and newest) weapon system on that chart, the AV-8 (Harrier) V/STOL aircraft, has approximately one-third the cockpit space that the F-4 aircraft has.

Exhibit 2-1

Cockpit Space and Information Requirements for Several Navy Aircraft Weapon Systems

Available Cockpit Space In^2

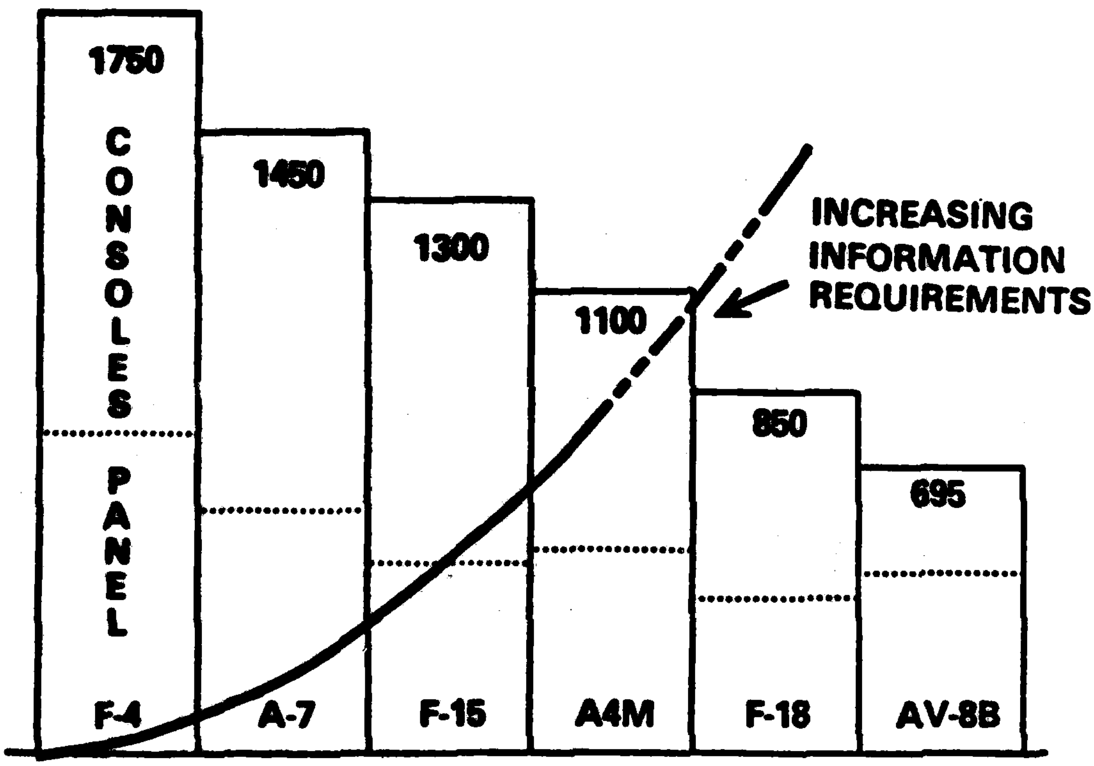
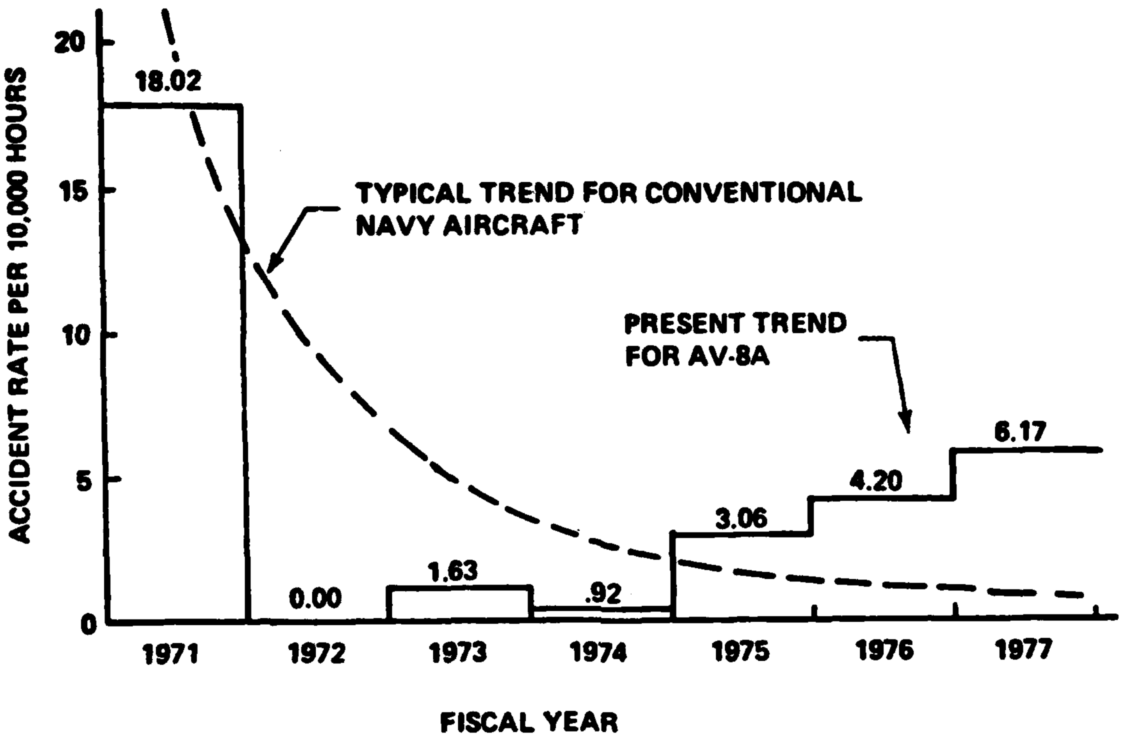


Exhibit 2-2

Trend of Accident Rates for Typical Navy Aircraft and the AV-8 Harrier



MAJOR ACCIDENT RATES SINCE INTRODUCTION TO USMC SERVICE 24 - TOTAL

Exhibit 2-2 shows that the V/STOL accident rate has been increasing the last few years. This is contrary to the experience typically encountered when new aircraft are introduced. Furthermore, "pilot factor" as a contributing cause seems to be high. With respect to this last point, the data shown in Exhibit 2-2 represent 21 accidents, 16 of which occurred in the V/STOL flight regime (i.e., conversion flight, landing, or takeoff). Of these 16, 11 had pilot factor as a contributing cause. It should also be added that the Naval Air Development Center has since initiated a program to provide human factors support early in the design of V/STOL aircraft.

Another prime example of systems complexity impinging upon accurate operator performance is the automated C^3I system. Commanders have to make crucial decisions on the basis of information flowing in from often remote locations. Since the information is filtered, distributed, and analyzed at numerous points prior to its arrival at the Command Post, the allocation of these functions to man and machines is critical. The Tactical Operations System (TOS) experience exemplifies what can happen if substantive HF efforts are not made early in the system development process. A combination of the message flow design and the hardware/software configuration created a situation in which most of the system nodes became information bottlenecks. In fact, the amount of information flowing into any one point was so great that it is questionable whether even a concentrated HF effort could have achieved an operable system once the configuration was fixed.

Many human factors difficulties would appear at first glance to be "common sense" matters, and easily corrected. A recent Navy publication (Office of the Assistant Secretary, 1980) reports the following HFE deficiencies on naval craft:

- Two systems having similar gas turbine-powered propulsion plants have entirely different display boards and control systems for these units.
- Different passive sonar systems use different processes and display formats for presenting similar types of information.
- Filters on the SPS-40B Surface Radar cannot be reached for routine maintenance.
- The emergency cut-off for the HP Air Flasks is difficult to locate and reach on the DD-963.
- The access hatch to the Turbine on the DD-963 is blocked by a catwalk.

Such problems are not so common-sensical or easily solved as one might guess. In many cases the total system configuration was not sufficiently conceived of in light of operator and maintainer needs, which was also the essential problem with the Army's TOS. Consequently, an HF retrofit might mean reconfiguring a bulkhead or hatch, or retraining operators and maintainers.

The preceding discussion describes what can happen if HF is neglected. The reverse side of the coin is: what is accomplished if HF expertise is heeded at critical points in the design process? Accomplishments cannot be pinpointed as dramatically as failures, since a smooth-working system does not attract the same attention as one that fails in its mission and/or is associated with error-related casualties and breakdowns. However, the article cited above makes a good case for the successful application of human factors in naval ships and aircraft, as reflected in the following excerpt:

> There is ample evidence that the problems observed can be solved. Many cases of excellent man-machine interface design were noted. The engine and electrical control consoles on the DD-985, for example, were well laid out and easy to read. The SLQ-32 and the WR-12 are examples of easy-to-use systems. Outside of the surface community, much can be learned from positive examples available in aircraft design. For example, the A-6 aircraft reflects careful attention to operator interfaces, with the result that the crew can effectively perform extraordinarily demanding and hazardous missions. Similar attention is being given to man-machine interfaces in the F-18.

One need not be restricted to the Navy to uncover HF applications. Both the Air Force and the Army have devoted substantial effort to optimizing the man-machine design characteristics of system under development. In systems as different as SOTAS and TITAN, changes in the spatial and functional task arrangements of personnel have succeeded in improving performance. Human factors applications in the Air Force are concentrated in the aerospace area, while in the Army such efforts are directed at an increasingly complex array of systems: small arms, anti-tank weapons, armored vehicles, helicopters, command-control, etc. Such issues as man-machine compatibility, portability, information overload, and computer interface are of special importance. Various specific applications could be enumerated, but it should suffice to point out that the work of HF staffs has contributed to the design of many systems, such work consisting of design evaluations/ recommendations, field tests, user requirements analyses, task analyses, training evaluations, etc. A series of reports by the Navy (Price & Sands, 1978; Price & Sands, 1979; Lewis et al., 1980; Lewis et al., 1981) and the Army (Army Research Institute, 1980) provides a comprehensive overview of such efforts.

Summary

The need for strong HF considerations in systems development should be clear by this point. Other examples are provided in

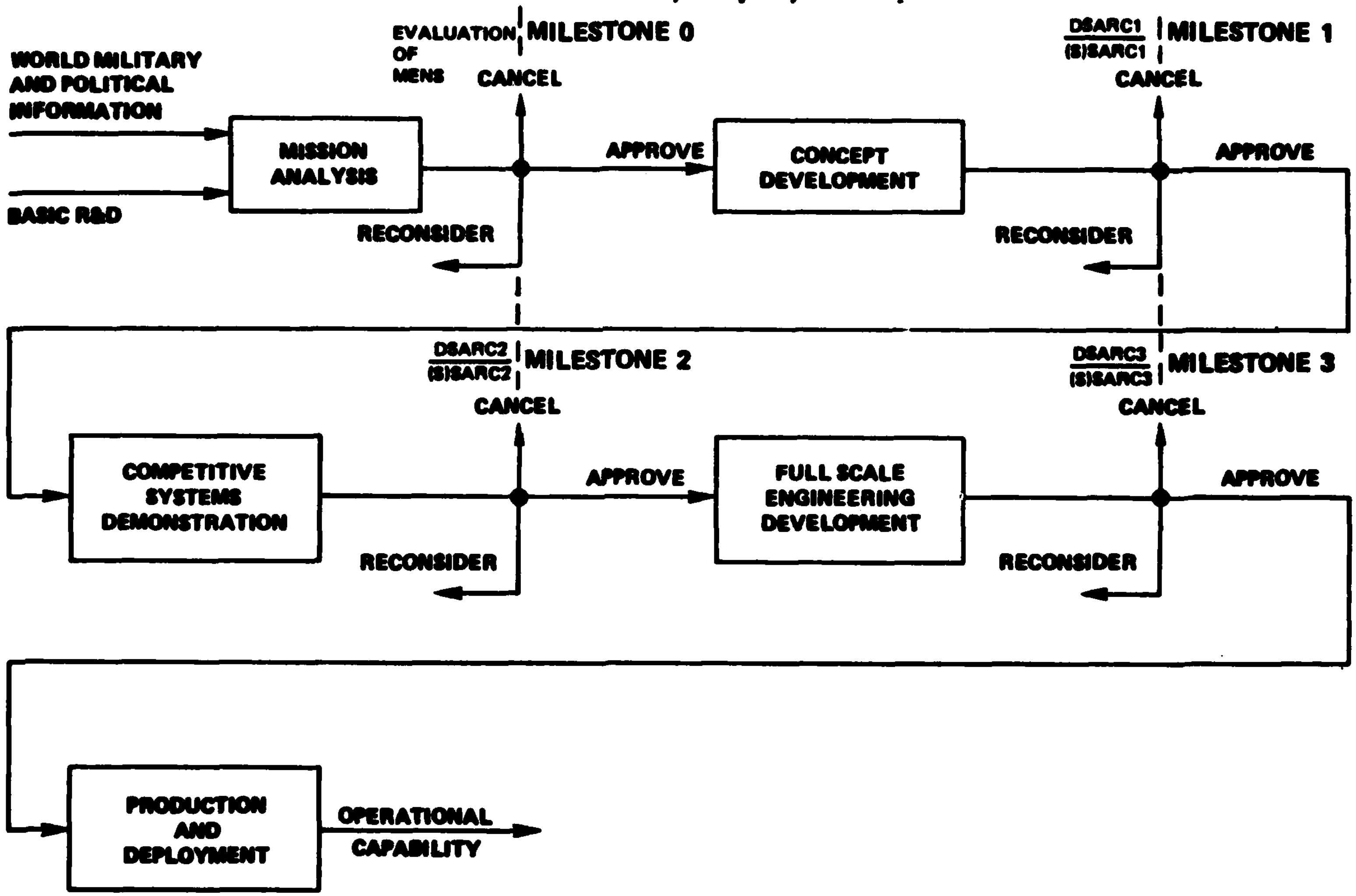
in the Phase I report (Price et al., 1980). The viability of a system will be affected by its compatibility with human performance, regardless of the size, complexity, or purpose of that system. To some degree poorly human engineered systems can be improved with HF fixes, but too often these are only palliative measures, due to the increasing inflexibility which accrues in the design of a system as it progresses into the development cycle. Too often, system developers omit a thorough human factors "front-end analysis," and the performance-related design factors create inadvertent problems that are compounded as the development process goes forward.

The Chronology of Weapon System Procurement

Basic Model

The Phase I report included a description of the system acquisition model that has been established for major military systems. The model is based on the guidelines and policies for major government acquisitions outlined in OMB Circular No. A-109 (1976). The purpose of the circular is to foster the integration of numerous factors (e.g., system requirements, costs, land concepts) in order to avoid past problems of cost overruns and premature commitments to full-scale development and production. DOD Directives 5000.1, 5000.2, and 5000.3 respectively provide policy, policy/procedures, and test/evaluation guidance for the acquisition process as it applies to military systems. These directives recently were revised to effectively augment their relationship to requirements for human factors R&D, the functional and detailed requirements for which are contained in military standards MIL-STD-1472B and MIL-H-46855. The basic developmental process is illustrated in Exhibit 2-3. There are four essential phases which precede production and deployment, and each phase may be conceived of as follows:

Exhibit 2-3
The Phases of the Military's Major System Acquisition Model



The phases leading up to the different milestones (MI) are the following:

Mission Analysis (precedes MI 0)--A comparison between the present technology status and what is needed.

Concept Development (precedes MI 1)--A study of the strengths and weaknesses of proposed alternative systems.

Demonstration and Validation (precedes MI 2)--a competitive demonstration of the chosen system(s).

Full-Scale Development (precedes MI 3)--The building and testing of the complete system.

The evaluation mechanisms for each phase except Mission Analysis are the (S)SARCs and DSARCs, the service and DOD-level formal reviews. The evaluation of the MENS by the Secretary of Defense constitutes the MI 0 evaluation. The purpose of the evaluations is to determine the viability of the system concept and progress. Based upon the conclusions and recommendations emerging from these evaluations, a decision is reached concerning whether or not to continue the development effort and concerning what modifications might be incorporated, given continuation.

Key Decision Points for Human Factors

The trend in DOD and Service-level documentation is to require human factors participation in all of the MI phases of major systems development. But one of the conclusions reached during the conduct of the present project is that human factors receives the least consideration when it is needed the most, during and immediately after the Mission Analysis phase. Exhibit 2-4 depicts decision points which are critical to the basic design of a system and to the exercise of human factors throughout the development cycle. The development of the MENS statement rarely includes direct input from HF laboratory or staff personnel. Since the system requirements follow directly from the MENS, the development of the system in respect to human requirements often can be incomplete. The appointment of the PM is also critical in that his selection and monitoring of the prime contractor should reflect a reasonably keen appreciation of human factors. The present report addresses these problems, specifically in the redefinition of the HF practitioners' role and in the proposed handbook for PMs.

Exhibit 2-4
Crucial Points for Early HFE Inputs

Variations from the Framework of the Acquisition Model

It would be naive to think that all major military systems are developed in direct conformity with the approach recommended

by the DOD. Some systems are the direct descendants of earlier ones, and thus "land running," so to speak. Thus, for economic reasons the early phases in the acquisition model may be only perfunctorily attended to, and some phases may be compressed. Other systems, however, evolve almost full-blown as the synthesis of various minor systems; such systems are not subject to the requirements for major ones. The danger here is two-fold and applies to both human factors and other, strictly technological, considerations. First, the minor systems themselves may be ill-conceived. Second, a composite major system will be more than simply the sum of its components. Fitting together small systems to produce a larger one should not be attempted without the careful planning implicit in the Circular A-109 model.

Finally, it is worth noting that recommendations for changes in the systems acquisition process have been advocated by the Deputy Secretary of Defense in a recent memorandum (1981). He points to a need for expediting the development of systems by reducing the number of DOD-level reviews (DSARCS), and leaving more of the key decision-making to service-level reviews ((S)SARCS). The MENS would be shortened substantially in length, the number of milestones would be reduced, and DSARCS would have more representation from the services. In general, this proposal would decentralize the acquisition process, giving the DOD less control over the initiation and design of systems and leaving the Secretary of Defense with less influence over preliminary planning.

The Concept of the Principal Product

As stated earlier, the principal product is the cumulative contribution of HF to the operability and maintainability of a system. Each of the developmental phases in the acquisition cycle yields a product; each product has distinctive properties of its own and cumulative effects upon the products of subsequent phases. A comprehensive discussion of the concept was presented in the Phase I report, and the necessary basic assumptions and actions can be found in Appendix C of the present report. Exhibit 2-5 shows the principal products which the HF staff should contribute in each of the development phases. A summary of these (with an example of each) is presented below, followed by a discussion of additional considerations regarding the principal product which have evolved during the present phase of the project.

A Brief Discussion and Example of Development Cycle Principal Products

A discussion of the phase-by-phase principal products along with a simple example will help to illustrate both the importance and nature of the principal product concept. A running example involving a C^3I system is used in order to point out the cumulative effect of HF-related decisions upon the nature of the system. The example incorporates considerations which have emerged from actual systems, and it reflects the same role-of-man issue utilized in the case study of the maneuver control system impact analysis (Appendix A).

Mission Analysis (Role of Man). (See Exhibit 2-6 for an illustration of this phase.) In general, the system developer must address the question of whether or not the proposed system is needed. This question is answered through a threat analysis,

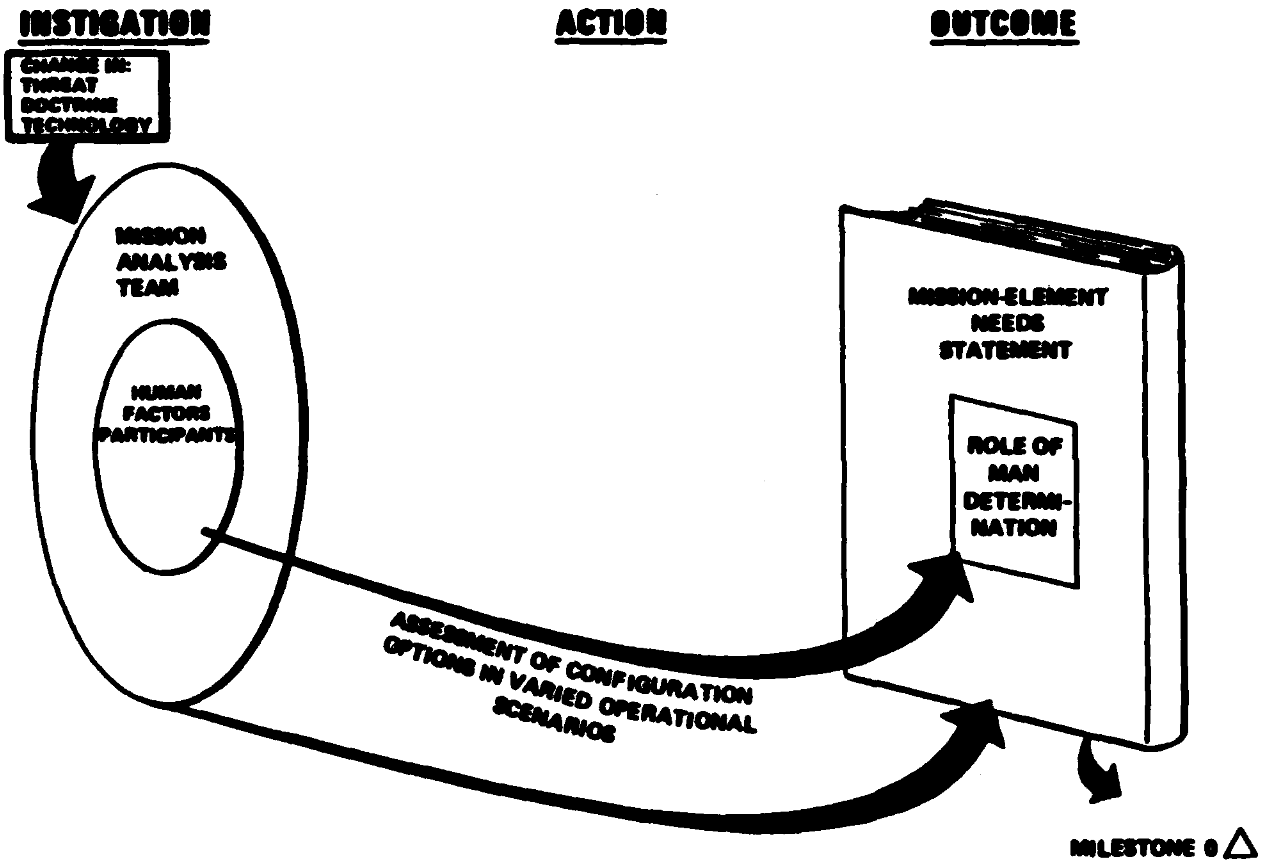
Exhibit 2-5

Principal Human Factors Products for Major System Development Phases

System Development Phase	Human Factors R&D Principal Product	Potential System Design Effects
Mission Analysis Phase	Development of the Role of Man as part of a Mission Element Needs Statement (MENS)	(a) Maximum mission flexibility (b) Maximum crew acceptance (c) Minimal crew size and costs (d) System recoverability
Concept Development Phase	Allocation of System Functions to Man as part of the Decision Coordinating Paper (DCP)	(a) Balanced automation (b) Mission sustainability/endurance (c) Optimum response to emergencies (d) Responsiveness to change
Demonstration and Validation Phase	Task Analysis and Determination of Human Factors Engineering Requirements	(a) High quality decision making (b) Productive and satisfying job designs (c) Minimal training costs (d) Minimal maintenance costs (e) Minimal retrofit and redesign
Full-Scale Development Phase	Design of the Optimal Man-Machine Interfaces	(a) Minimal response delays (b) Optimal accuracy/reduced errors (c) Optimal survivability (d) Optimal user compatibility

Exhibit 2-6
Human Factors Principal Products

–FIRST PHASE : MISSION ANALYSIS–



which provides the basic justification in the MENS and helps to determine the system mission. The operational conditions and system functions are then identified, and a parallel process is conducted to determine the functions of man under these same conditions. The principal product is the Role-of-Man Statement resulting from these activities. The statement should include the following considerations:

- The effects of alternative system concepts upon man (habitability, safety, etc.)
- The relative advantages of alternative human functions for various system concepts.
- The relative disadvantages of alternative human functions for various system concepts.
- The required human performance and capabilities for each function.
- The implications of each alternative system concept for training, manpower, life support, logistics, etc.).
- A list of human factors design features which could facilitate successful system operation under each alternative concept.

Example - The example is intended to illustrate the fundamental characteristics of the principal products; it is not intended to suggest an idealized C^3I system design. Such systems are too complex and varied to allow such an undertaking. The system design concept to be analyzed provides that the nodes within the system serve as receivers, filters and transmitters. Thus, information from the field flows upward through hierarchies, with the nodes at each level reducing the information such that it can be utilized efficiently by the end-user at division command. Given this system concept, the role of the operator must be

determined. The decision is to employ the non-dedicated user as operator.

The non-dedicated, or "casual," user idea has certain advantages. First, the impact of battlefield conditions upon the availability and performance of highly trained specialists will be minimized. Thus, personnel with different backgrounds can step in when necessary. Second, such an approach limits the necessary allocations for training. Third, the projected use of non-dedicated users focuses attention upon the development of software. Therefore, there is no gray area between training and technology which can create ambiguity for systems developers in respect to their allocation of resources.

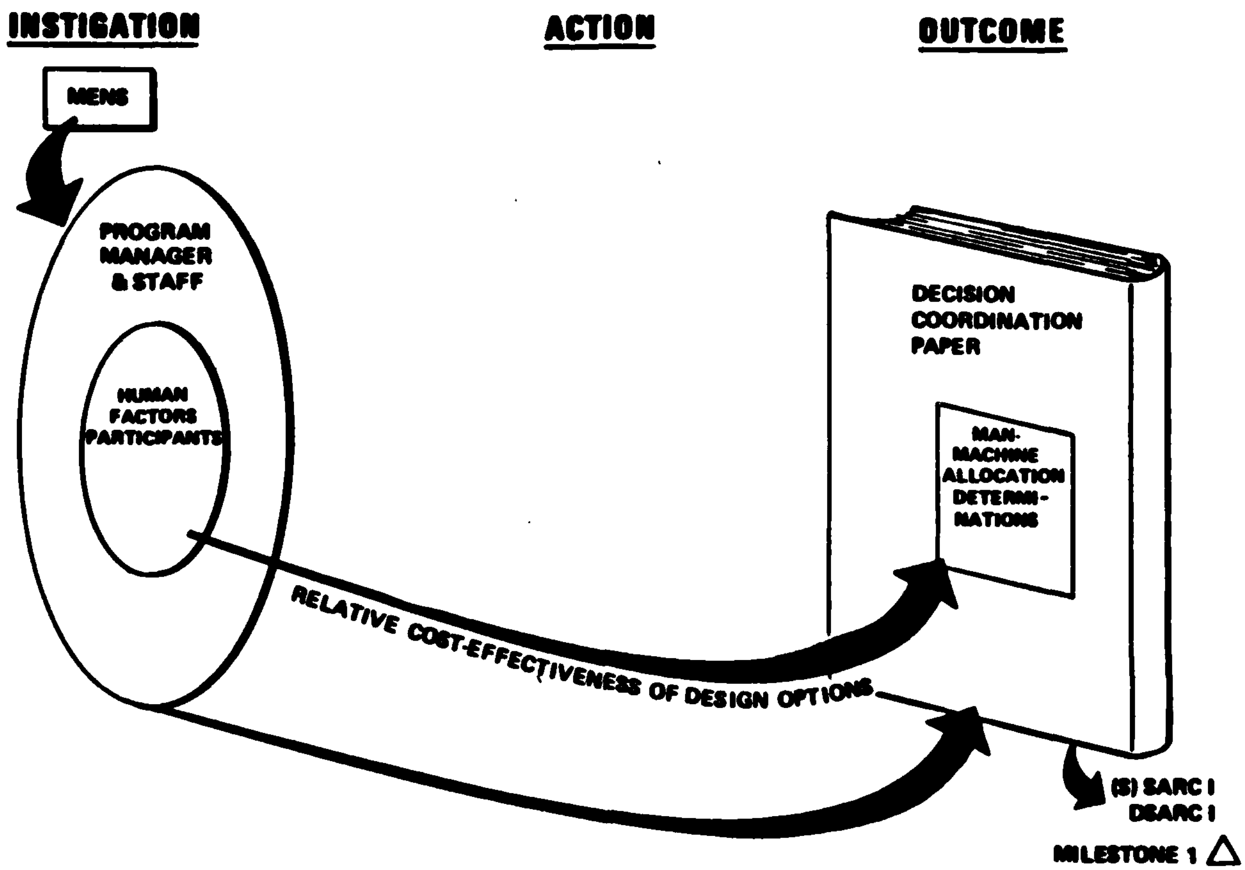
The main disadvantage of using the non-dedicated user is the burden placed upon automation. A great deal of equipment and software is necessary to drive the system operation, and thus, mobility may be restricted. However, in the present case it is assumed that recent advances in technology will provide the capability for complex, yet compact, automated elements.

Concept Development (Allocation of Functions). (See Exhibit 2-7 for an illustration of this phase.) The system developer studies the alternative concepts which evolved during the Mission Analysis phase. For the concept selected, the HF principal product is allocation of functions to man and machine. This should be documented in the DCP. In modern systems this usually means a decision about the degree of automation. The basic steps in the allocation process are:

- Specify the human factors criteria selected for allocation of functions (e.g., response time, error rate, cost, safety, etc.).

Exhibit 2-7
Human Factors Principal Products

—SECOND PHASE: CONCEPT DEVELOPMENT PHASE—

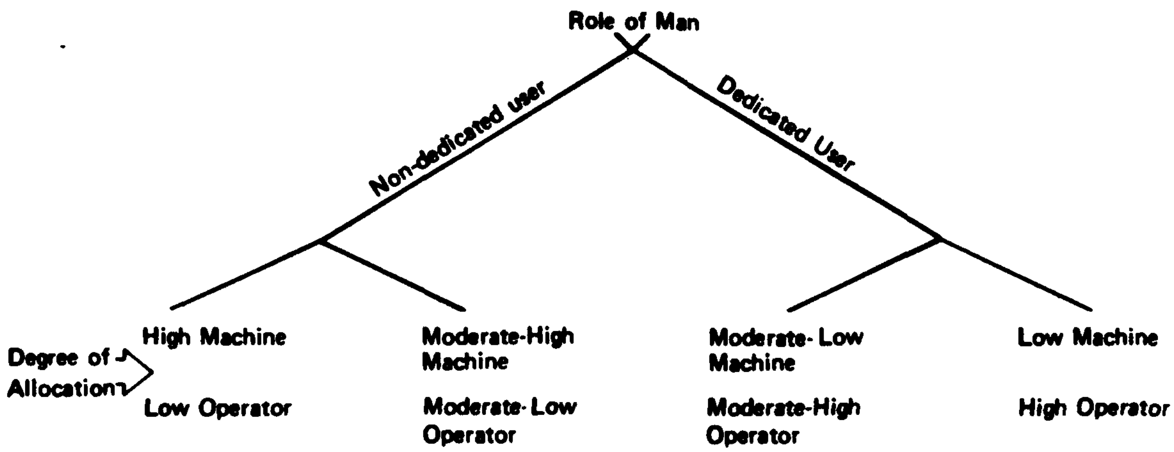


- List alternative allocations of each function to: one or more operators/maintainers; machine only; combination of man/machine.
- Estimate feasibility for alternative allocations of each function, considering the following:
  - human performance capabilities required
  - machine capabilities required
  - workload
  - user acceptance
  - bottlenecks
  - mission impacts
  - criticality of functions.
- Evaluate the alternative allocations of each function. All allocations of functions should be listed in a matrix and systematically compared with the criteria formulated in the first step.

Example - In the Mission Analysis phase the role of man selected for the preferred C^3I concept was that of the non-dedicated user. Given that the chosen concept and associated role of man are adhered to in the present (Concept Development) phase, the decision tree in Exhibit 2-8 shows that the general range of possible man-machine allocations is to some extent predetermined.

Exhibit 2-8

Degree of Functions Allocations to Man and Machine as Consequence of Role Determination



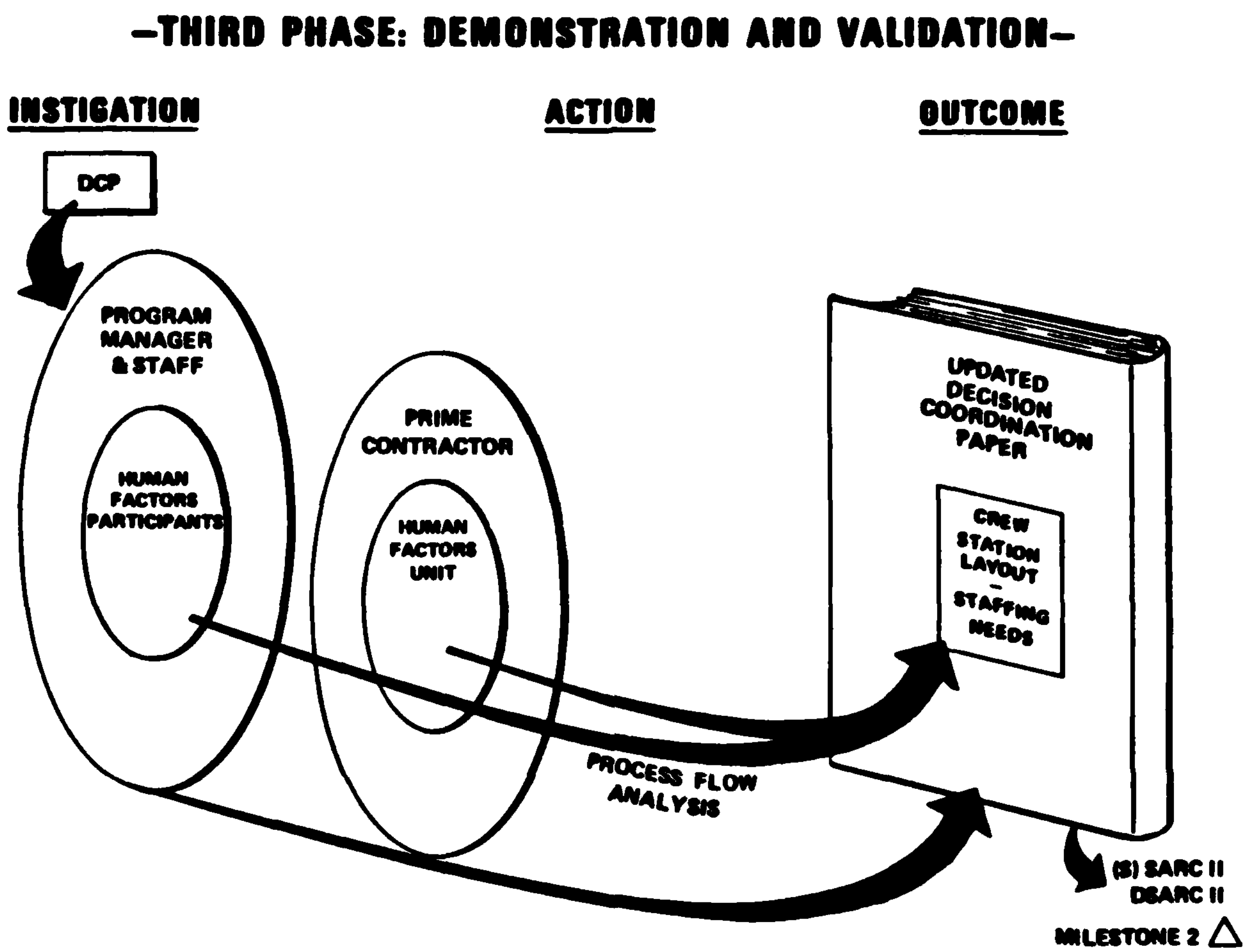
If operators are to be non-dedicated users, moderate-to-high machine allocation is required. Thus, while the criteria for the allocation of functions will be about the same as those for most C^3I systems (e.g., information bottlenecks, response time, cost, etc.), the alternative allocations evaluated against these criteria will be restricted to the range represented by the left-hand side of the scale, a range reflecting emphasis upon machines (automation). Within this range the feasibility of alternative allocations must be determined. For example, in the area of user acceptance there is a real question of operator overload in C^3I systems. Heavy allocation to machines will theoretically provide the answer to this problem, but may frustrate the needs of operators to perform at the highest skill level. If only non-dedicated users are employed, this should not be a problem; however, the possible use of some specialists as operators should be addressed in this regard.

At this point the crux of the human factors issue emerges: What if the Mission Analysis principal product (role of man as non-dedicated user) had not been derived? System functions might have been allocated in such a way that successful operation would have required operator expertise far exceeding manpower levels and conflicting with realistic combat scenarios. Assuming that the non-dedicated user is the best role-of-man alternative, the failure to derive this product initially might result in functional allocations and subsequent training/HF decisions that conflict with efficient system performance.

Demonstration/Validation (Task Analysis & Human Factors Engineering Requirements). (See Exhibit 2-9 for an illustration of this phase.) The general purpose of the effort at this stage is to demonstrate the selected system concept and test its feasibility with regard to mission requirements. Two closely linked principal products should be developed in this phase: task analysis and human factors engineering requirements. Given the allocation-of-functions product of the Concept Development phase, the following actions should be taken by the HF staff in Demonstration/Validation:

- Participate in construction of mock-ups.
- Conduct task analyses (functional analyses, sequence analyses, etc.)
- Derive station arrangement, workspace, console, and C/D concepts.
- Conduct simulation/mock-up evaluations.
- Determine human performance and HF engineering requirements.
- Participate in prototype development.
- Participate in DT/OT.

Exhibit 2-9
Human Factors Principal Products



- Perform additional task analyses on prototype, as needed.
- Validate HF engineering requirements.

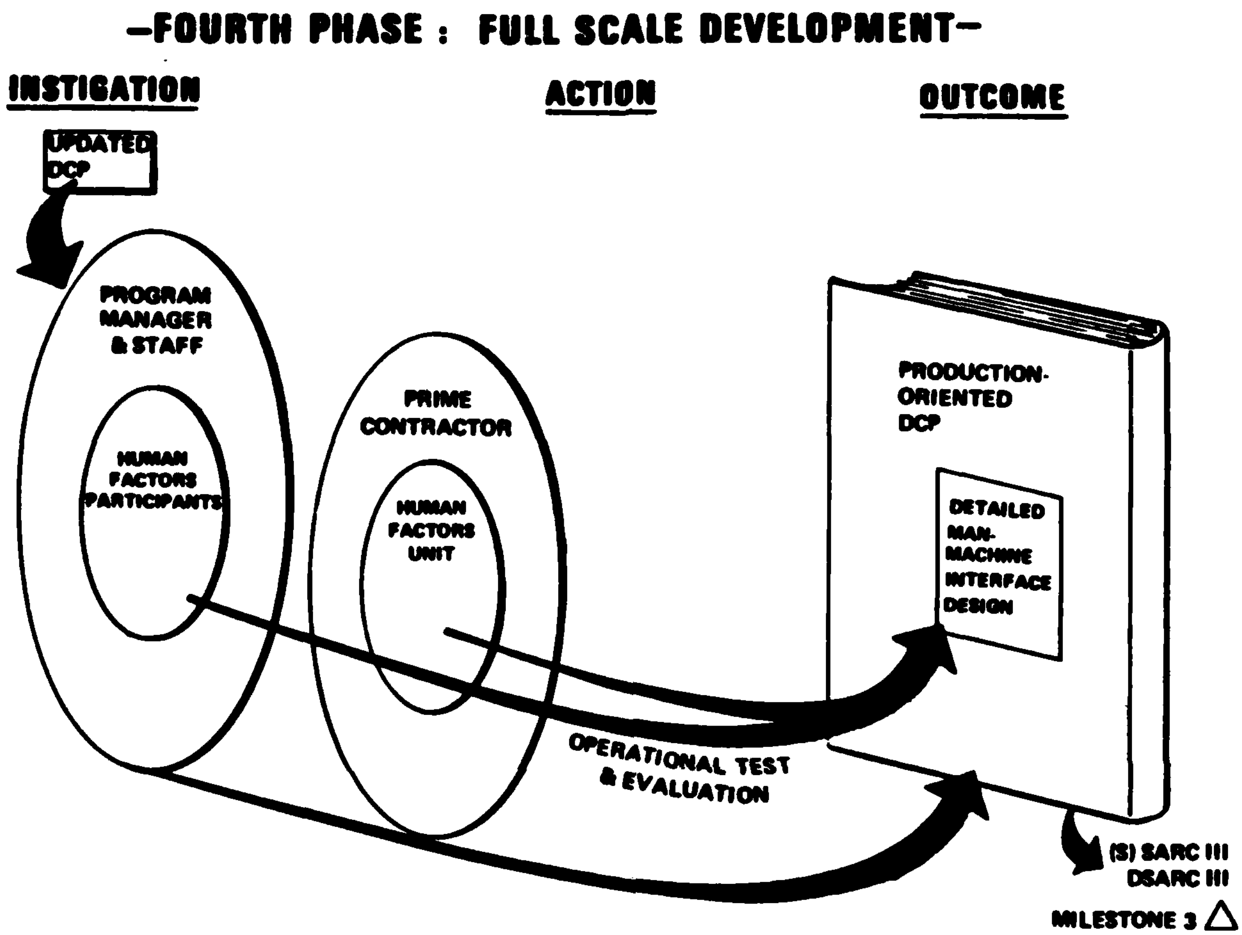
Task analyses should be performed iteratively on successive refinements of the mock-up and prototype until the human performance aspects of the system are within the capabilities of the projected operators and maintainers. The HF engineering requirements will be derived from the task analytic findings.

Example - Given that operators will be non-dedicated users and that the system functions are allocated largely to machines in our hypothetical C^3I system, the HF engineering requirements will be critical to successful operation. Mock-ups and prototypes which incorporate advanced interface concepts must be constructed so that personnel who are not highly trained in the use of computerized systems can use the consoles and keyboards. A universal symbology, simple prompts, immediate error notification, and data entry via a typewriter-style keyboard are concepts that might be tested. The estimated rate and volume of message flow throughout the system should drive both the task analyses and formal evaluations. Also, since the non-dedicated user may have any one of a number of specialties (e.g., planner, analyst, runner, etc.), intertask work flow might be analyzed.

<u>Full-Scale Development (Optimal Man-Machine Interface)</u>. (See Exhibit 2-10 for an illustration of this phase.) The system developer is faced with the decision of whether or not to accept or modify the prototype system built in the Demonstration/ Validation phase. For HF proper, this phase entails the consideration of design alternatives in respect to man-machine interface.

Exhibit 2-10

Human Factors Principal Products



Essentially, the HF staff must further refine and evaluate interfaces, which will entail the following considerations:

- fulfillment of human factors requirements
- conformity to human factors design criteria
- quantitative measures of system performance
- detection of undesirable design or procedural features.

Example - The developers of the proposed C^3I system will require that data be formatted and entered by operators within the constraints of various environmental conditions and specific time, and accuracy requirements. Due to proposed engineering changes in the prototype, the display size on the console is to be slightly reduced. The HF staff, therefore, will be concerned with the sensory/perceptual characteristics of the smaller display which might affect length of lines, number of lines, menu size, etc.; these are factors that could appreciably influence operator performance. Thus, the final human factors effort must involve a fine tuning of the interface characteristics of the display in light of these engineering design changes and refinements.

In summary, both the importance and the interdependence of the principal products for the different acquistion phases should be clear by this point. The initial role-of-man analysis and following allocation of functions provide the basic direction for task analysis and HF engineering requirements and, finally, man-machine interfaces.

Should the first step be incomplete, the entire human factors effort will be in jeopardy. Too many systems either have been failures or have required costly redesign for precisely this reason.

Additional Comments on the Principal Product Concept

Both the conduct of the case studies and extensive contact with personnel representing HF labs and systems development organizations have led to two primary conclusions concerning the principal products: (1) the need for the concept is more urgent than ever, and (2) there are currently numerous problems regarding the proper implementation of the principal product in systems development. With respect to the first point, the increasing need for this concept stems primarily from the effects of rapidly advancing technology upon the complexity of present-day systems. This fact has been made clear in both the present and earlier reports. Regarding the question of principal-product implementation, a number of observations have been made:

1. HF personnel often have little or no voice in the Mission Analysis proceedings, in which the critical Role-of-Man analysis should be conducted.

2. Human factors personnel serve infrequently on DSARC/(S)SARC panels, so that, consequently, these panels rarely confront human factors issues.

3. HF decisions often are informal and difficult to capture. A thorough documentation procedure is necessary if HF laboratories and departments are to represent principal products as real contributions to system design.

4. Since some systems are relatively minor variations of earlier ones, for purposes of economy the new system may essentially begin development late in the acquisition cycle (e.g., at the Demonstration/Validation stage). The principal products of predecessor systems in such cases must be recognized as the sources to be considered in the development of the new system.

5. Since systems are extremely variable from several standpoints (configuration, size, mission, degree of automation, etc.), there exists a need for a tool that can be used to link the principal product concept to system-specific HF engineering issues.

The first three observations reflect the need for expanding the role of the HF practitioner, a need discussed in the earlier interim report as well as in the present report. However, points (4) and (5) require a bit more elaboration. First, since many systems are variations of earlier ones, only a clear understanding of the predecessor, or "reference," system HF data and issues can prevent the recurrence of prior human factors deficiencies. This is especially important in cases in which there are organizational pressures to incorporate as much of the reference system(s) as possible into the new one.

In regard to the question of directly linking the principal product notion to system-specific HF issues and problems, a <u>taxonomic</u> approach, such as that shown in Exhibit 2-11 could serve as a first step by illuminating the HF engineering commonalities and differences of various systems. The taxonomy could also serve as the organizing principle for a second step, the creation of a <u>human factors data base</u>. This could be used to consolidate into a principal product reference system the human performance functions and HF actions/issues which have emerged during the acquisition of different systems.

As a final note, it should be clear that the principal product is not intended to be a rigid specification. The principal product is both a process and a concept. As a process, it embodies the kinds of HF considerations which must come into play at the various stages of system development. As a concept,

Exhibit 2-11
Tentative Framework for HFE Issues-by-System Taxonomy

Principal Product	C^3I		Fighting Vehicles
	Communications Maintenance	Information Routing	Refueling in Field
Role-of-Man Analysis	Role of operator in maintenance	–Dedicated/non-dedicated user –Effects of weather, lighting, etc. upon performance	Effects of enemy fire upon performance of exposed personnel
Allocation of Function	Feasibility of automated test equipment	Feasibility of: Automated correlation Automated error detection	Use of booster pumps
Task Analysis HFE Requirements	Task sequence in antenna	Analysis of information flow Keyboard configuration	
Optimal Man-Machine Interfaces		Effects of prototype redesign upon: Keying in data Reading display	

it is a focal point around which come together all the concerns of the human factors community regarding the performance characteristics of military systems.

CHAPTER 3
THE COST-BENEFIT APPROACH: IMPACT ASSESSMENT

Background

There is a basic generic affinity between the concept of cost-benefit analysis and the concept of human factors engineering. Both were originally conceived as means to prevent or minimize the commission of gross errors. There is an even broader affinity: Cost-benefit analysis is based on economics, and human factors engineering is a part of the larger engineering enterprise. Both economics and engineering focus on return on invested resource (ROI). In economics, the resource is money or its equivalent; in engineering the resource is likely to be time or energy or both. Insofar as time and energy can be converted to dollars, both fields have a common objective: efficiency.

Given these commonalities, the idea of evaluating the contribution of HF to military system developments is an appealing one, particularly in the sense that the "efficiency" of the development process could be enhanced as well as the "efficiency" of the resultant system.

This study recommends and develops a conceptual methodology for using one form of the cost-benefit approach to assess the contributions of human factors in military system development. As stated earlier, the major components of the conceptual methodology developed during Phase I are:

- A rationale for human factors considerations in system development with specific analyses for Human Factors Principal Products during the major development milestones and other system specific efforts and technology-base issues (Chapter 2).

- A multi-step Impact Assessment Framework for formally measuring and relating human factors contributions to military system: cost control, capability, and compatibility.

Integration of HF Principal Products and Impact Assessment

The human factors principal products for each major phase of the system acquisition were described in Chapter 2 and are summarized in Exhibit 2-5. Their importance to the impact assessment implementation will now be discussed.

The principal products from each phase of the system acquisition are a meaningful way to represent the scope of human factors in a military system development. These phased products are intended to vary in content and specificity from the very conceptual requirement level to the very detailed design level, just as is the case with products of systems engineering, logistics, etc. during each phase. A detailed description of the principal products is presented in Appendix C.

In general, each HF principal product will include:

- A check-off list of critical HF issues tailored to the phase of system development. Past experience and documentation on reference systems or functions and new technology are major inputs to the check-off list.
- Empirical and/or analytical findings from HF analysis, design, test, and evaluation techniques carried out during the phase of system development. Examples of HF techniques include: mission profile/scenario analysis, function flow diagrams, decision/action diagrams, task descriptions, etc.

- A specific set of recommended HF actions that are defined in terms of system- and personnel-related empirical measures (e.g., firing rate, mean time to repair, human engineering deficiencies, etc.).
- A preliminary translation of the actions in terms of human factor and system engineering metrics and their expected primary impact areas. This translation will normally be a narrative discussion.
- An HF management plan update for the remainder of the current phase or for the next phase of the system development.

In many instances the analysis of the human factors actions can stop at this point and will not require a formal impact assessment. For example, if the benefits of an action are self-evident (e.g., safety) and the expenditure to achieve the benefits is within a program manager's selected budget threshold, then a formal benefit-cost impact assessment is not essential.

On the other hand, for those human factors actions which have substantial input and output uncertainty, resource allocations competition, high visibility, or simply need an analytical demonstration of their worth, the 10-step impact assessment framework shown in Exhibit 3-1 can be used to translate quantitatively the expected impacts in terms of system-mission cost, capability, and compatibility. A description of each of the 10 steps is provided in Appendix D to this report.

<u>Linking Human Factors Changes to System Cost, Capability, and Compatibility</u>

As noted previously, HF is an activity directed toward the goal of system efficiency along a major route that can be labeled

Exhibit 3-1

Impact Assessment Framework

FORMULATING THE IMPACT ANALYSIS

1. Establishing the Problem, Goals, and Criteria
2. Defining the Alternative Solutions
3. Specifying the Baseline
4. Preparing the System Definition Statement
5. Selecting the Impact Areas, Metrics, and Performance Measures

CONDUCTING THE ANALYSIS

6. Selecting/Constructing the Impact Assessment Model(s)
7. Collecting and Processing the Data
8. Setting the Conventions for the Analysis
9. Estimating and Evaluating the Impacts

PREPARING AND INTERPRETING THE RESULTS

10. Presenting the Results, Associated Uncertainties, and Bounding Conditions

"the prevention of gross errors." Most of the criticisms of contemporary military systems reveal that gross errors can be made and are made in the decisions among design alternatives.

One of the reasons that it is always difficult to prove the value of HF in a syllogistic fashion is that the absence of error can never be tied to a single cause. The logic has always had to be of the form: No HF was done; a design error was made; hence it is conceivable that the design error would not have been made had HF been done. This type of reasoning is not very powerful or convincing.

A related weakness stems from the fact that there appear to be some systems that work rather well (are efficient), and upon which little or no official HF was performed. Engineering folklore can be read to suggest that a reasonably experienced or alert PM has learned some rudimentary HF and can be his/her own HF specialist by the routine exercise of a modicum of "common sense." This approach, however, has usually only been effective when "lessons learned" from a similar or predecessor system are available.

The negative folklore cannot be entirely refuted by the logic of negative cases. Consequently, there has arisen a growing sense that more powerful means of persuasion were required.

Our basic position is that the combination of the concepts of human factors principal products and that version of cost-benefit known as impact analysis could constitute such a more powerful means.

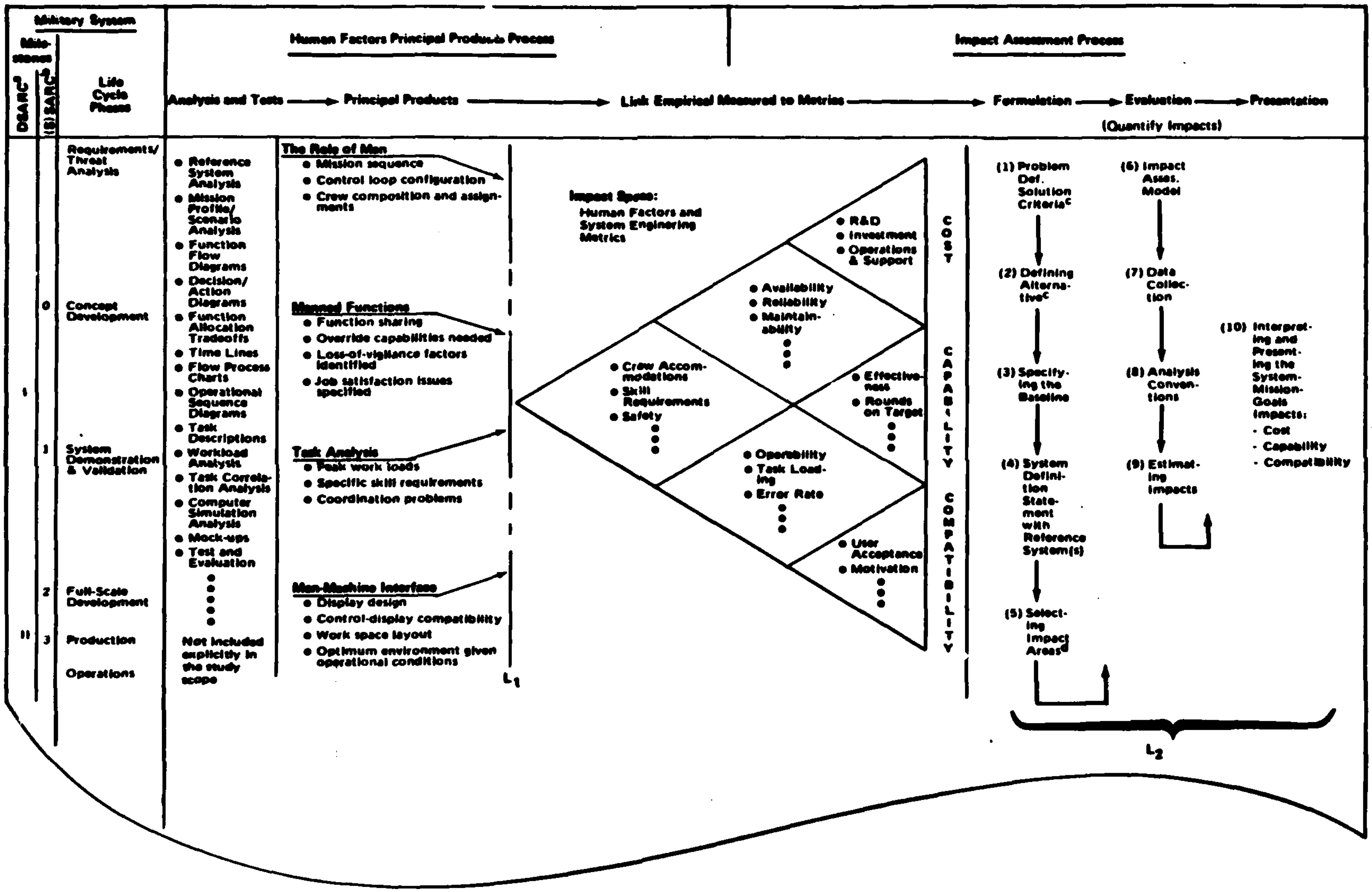
One advantage provided by this combination is that it tightly ties what the HF practitioners do in the system development process with what the other principal participants are doing. These links are manifested in the first instance by a co-adherence to the schedule-of-events in system development--regardless of whether that schedule is the official DOD version or some ad hoc variation. Secondly, the principal product idea leads to a tangible HF contribution, the substance and timing of which are predictable. In other words, the managers of the system development process can be given specific expectations about what the HF practitioners are doing to facilitate the system development process. If necessary, such managers can then make an equivocal albeit subjective judgement on the value of the contribution. They can respond to the narrow but realistic question: Were my expectations met?

The framework of impact analysis permits that same judgement to be made in both a more sophisticated and a more objective manner. Impact analysis provides a way of asking: What would have been the consequence of not having the HF product? What could the wrong decision have cost?

Linkage Between HF Principal Products and the Impact Assessment Framework

The basic relationship between the HF principal product recommended actions and the impact assessment framework is illustrated in Exhibit 3-2. A brief description of the formal linkage between the human factors principal product recommendations to change a system design and the implications of that change for the cost, capability, and compatibility of the system is given next.

Exhibit 3-2
Linking Human Factor Changes to System-Mission Impact Areas



[a]As per FY 82 plan for OSD review of major system acquisitions.
[b]As per historical review permits in a major systems' acquisition process.
[c]Derived directly from Human Factors Principal Products.
[d]Derived directly from the impact space and the Principal Product.

L1 — Links the empirical findings and recommendations in the Principal Products to the *expected*, primary impact metrics.

L2 — Links the Principal Product impact metrics formally to the mission-system impact areas of: cost, capability and compatibility.

The linkage between the human factors empirical findings and the impact areas consists of two components (depicted by L_1 and L_2 in Exhibit 3-2). A simplified illustration of the process is shown below.

Human Factors Empirical Findings and Recommendations	$\xrightarrow{L_1}$	Human Factors and System Engineering Metrics	$\xrightarrow{L_2}$	System-Mission Impact Areas

Linkage L_1 within the scope of the HF principal product, and linkage L_2 is comprised of the impact assessment methodology.

On the left side of Exhibit 3-2, a typical list of human factors analysis activities is shown. Based on these analyses, a number of specific deficiencies and recommended changes are determined about the role of man, his allocated functions, his tasks and human engineering requirements, and the man-machine interfaces over the system development-acquisition cycle. These empirically based measures are then translated, via linkage L_1, into a set of common or related human factors and engineering metrics.

The metrics are depicted as cells within a triangle (in the center of Exhibit 3-2). The metrics are related formally to the system-mission impact areas of Cost, Capability, and Compatibility via linkage L_2, the impact assessment methodology. The location of the metrics in the cells within the triangle indicates an expected first-order relationship with the impact areas. Only a few example metrics are shown in the exhibit. The diamond-shaped cells contain metrics that are common to two impact areas. For example, the metric reliability is shown in Exhibit 3-2 as having a first-order association with impact

areas Cost and Capability because it is located within the diamond-shaped cell that is defined by the intersection of the Cost and Capability diagonal columns. Metrics within a triangle-shaped cell are expected to have a primary association with the impact area indicated above the cell. For example, the metric Operation and Support Cost is shown in Exhibit 3-2 as having a primary association with the Cost impact area.

When a human factors change involves all three impact areas the linkage would be modeled in terms of a combination of specific metrics from two or more cells. Let us take an example, in which a human factors change is mapped onto the metric Crew Accommodations, which has a first-order association with the Cost and Compatibility impact areas (it could also be related to the capability impact area) via a metric-metric relationship such as: Crew Accomodations to Task Loading. The latter metric is in a cell in Exhibit 3-2 related to the Capability metric area. A preliminary list of metrics, based on our findings in the Phase I portion of this study is presented in Appendix E. Eventually, a comprehensive set of metric terms that will provide a standard, common vocabulary for human factors and systems engineering practitioners should be developed.

Using the Impact Assessment Methodology

Linkage L_2 consists of the impact assessment process. For those HF actions that require formal quantification of their costs and benefits, the 10 steps listed in Exhibit 3-1 would be carried out.

The impact assessment methodology is designed to assist program managers who would use analytical help or products in their HF-related decisions, and to offer guidance to those who

would provide the analytical help. A fundamental aim is to provide a tool for achieving parity in human factors participation in military system development programs.

Toward those ends, the impact assessment methodology can be used in the following ways:

- As a Discipline - to ensure that essential steps are carried out completely and consistently across different impact assessments. The methodology will help to organize materials, direct attention to the proper issues, and demonstrate that impact assessments are not limited only to issues that are quantified in terms of dollars.
- To Compare Alternatives and Select the Preferred One- in terms of their mission-system cost, capability, and compatibility values.
- To Formally Introduce HF Parameters into the Design Process along with Cost and Capability-for consideration in the design tradeoff decisions.

The question of when an impact assessment should be initiated does not have a simple, cookbook answer. Instead, the answer is dependent upon a number of contingencies, many of which involve political, judgemental, or intuitive considerations. The key decision issues appear to be: (1) Is a quantitative interpretation required for the decision-maker to assess effectively the recommended HF actions? (2) Is the problem amenable to a formal impact assessment (that is, can an impact assessment provide the required insights and precision)? and (3) Can the impact assessment be done within reasonable time and resource constraints (including available data, expertise, and models)? These three issues are interdependent, particularly (2) and (3).

In an attempt to gain insight into the practicality of applying the impact assessment methodology to HF actions, two case studies were initiated: the F-18 (Navy) and a hypothetical Command/Control System (based on TOS/SIGMA for the Army).

Each case study entailed developing an HF principal product and applying the impact assessment methodology to a particular HF-related action. The documentation for each of the case studies is included in Appendix A, and the findings from these studies are discussed in Chapter 4.

CHAPTER 4
CONCLUSIONS

This chapter contains findings and recommendations. The findings address the following questions:

(1) Are the conclusions of the Phase I effort still valid after the case study exercise?

(2) Is the HF Principal Products and Impact Assessment Framework (PPIAF) approach applicable to the evaluation of HF contributions to system development?

(3) If applicable, is the Human Factors PPIAF approach practical and worth the effort? This question is particularly important to the impact assessment process.

(4) Does the Human Factors PPIAF approach call for a redefinition of the role of the HF practitioner?

In addition, the major constraints experienced during the case studies are noted.

The recommendations present several action items that are essential to improve the state of the art in the implementation of the Human Factors PPIAF approach.

Conclusions of the Phase I Study

The Phase I effort concluded that:

- A conceptual basis for relating HF contributions can be defined.
- The HF contributions are measurable.
- A methodology for evaluating HF impacts is feasible.

Our Phase II findings are that these statements are valid, but that there are important, pragmatic qualifications regarding their applicability and practicality. The HF principal product outline and impact assessment methodology presented in Phase I are somewhat ideal. During Phase II, those concepts were made considerably more realistic from the standpoint of their implementations and interrelationships. We also learned that there are several constraints that the HF principal products and impact assessment methodology must and can deal with. These constraints are discussed next, along with the issue of practicality.

Applicability and Practicality of the Human Factors PPIAF Approach

The case studies provide enough of an experimental basis to allow the conclusion that both the HF principal products and the impact assessment methodology are applicable to the identification and analysis of HF issues in military system design. They provide a logical and substantive improvement over the currently constrained methods for performance and evaluation of human factors in the context of military system development.

The question of practicality cannot be answered so unequivocally, in part because the case studies were carried out not in situ but rather post hoc, and in part because the case studies do not represent the full spectrum of HF-system development combinations likely to be incurred in reality. We can conclude, that unless a system development program has been carefully documented, that it is impractical to attempt an HF principal product or impact assessment analysis in a post hoc setting. The major reason for the proviso is the lack of relevant, valid data. Also, because of the many hypothetical

premises necessitated by a lack of data in the case examples, we could not empirically investigate whether impact assessments tend to provide results that are any different than those provided by subjective arguments supporting interim recommendations at, say, stage L_1 in Exhibit 3-2. Obviously there will be a set of cases for which subjective arguments are sufficient and appropriate. However, when there is high uncertainty, resource allocation competition, high visibility considerations, and analytic support for other candidate and non-HF actions, then the use of the impact assessment methodology is in our judgment an appropriate and pragmatic decision. With regard to the impact assessment methodology data and model requirements, we find that since it builds upon the Life Cycle Cost and Integrated Logistics Support analyses called for in current DOD directives and instructions for major system developments, it is no less feasible than they are. However, these types of analyses do require some expertise that human factors practitioners might not have. All of these analytical methodologies are most practical if they are implemented during the system development process.

Though the HF impact assessment methodology is designed as an independent activity, it is intended to chronologically follow the development of the HF principal products. The principal products provide essential inputs to the first five steps of the impact assessment methodology (See Exhibit 3-1).

There appear to be two major constraints on the successful performance of an HF action impact assessment. The first and paramount are data constraints, and the second are methodological difficulties. Each of these is briefly discussed below.

Data Constraints

Data constraints include problems that limit the impact assessment analysis because data are:

- insufficient (or non-existent)
- unvalidated
- inconsistent
- non-retrievable (or at least not conveniently).

Though the lack of adequate data was the most severe constraint experienced in the case studies, it is a problem that can be treated in a relatively straightforward manner. What is needed is a deliberate and consistent documentation and storage process such as is called for in the recommendations at the end of this chapter.

Methodological Difficulties

These require additional, sometimes significant, effort and expertise to be dealt with properly. Several of the more prevalent methodological difficulties are:

1. Isolating Human Factors Impacts. It is very difficult--and frequently impossible--to accurately isolate the individual impacts from aggregated impacts when the human factor impacts are not independent of one another, or when the individual contributions to the overall, aggregated impacts are not individually measurable.

In such instances, it is necessary to aggregate all the concurrent human factors-related actions. When the impacts from the aggregated human factors actions cannot be distinguished

accurately from the impacts of the non-human factors actions, an approximate attribution of the total negative and positive impacts on the military system to the contributing actions is required. A conceptual basis for such attributions can be found, for example, in Saaty (1979) and Ostrofsky (1977). It should be noted, however, that isolation of HF impacts should not be so difficult in a system under development where HF practitioners were permitted to "practice" the PPIAF approach.

2. Utilizing Sophisticated Techniques. Many of the models that can incorporate intangible impacts are difficult to use and understand. When a complex procedure is needed to assess the causal relationship(s) between an action and an impact, it will often be necessary to employ analytical specialists to apply the technique and interpret the results. The resources needed to do the analysis are part of the cost-impact assessment decisions.

3. Component vs. System Impacts. Often the focus of the human factors R&D activity will be on an individual procedure or component, and not an entire system. When the procedure or component is changed as a consequence of the human factors related actions, the impact should be related to the system's mission capability, cost, or compatibility. It is often difficult to relate the results of an analysis of a part to the whole. In many such instances, an opportunity cost argument for the "freed" resources or improved capability is the most appropriate explanation of the impact.

4. Tracking Impacts from Phase to Phase. The conceptual process, as envisioned, calls for the consideration and assessment of human factors impacts throughout the development phases of a military system. Each phase represents a window of opportunity

for human factors-related actions. The impact assessment framework is intended to be applied to the candidate actions within each phase. In keeping with the baseline concept used in cost-benefit analysis, the projected impacts are evaluated relative to a specified baseline. When design or procedure is changed, the baseline for subsequent impact assessments is also changed. Consequently, the baseline will be continually updated as changes are introduced over the system development phases. Thus, an impact forecasted in one phase will not necessarily be additive with impact forecasted (claimed) in earlier or subsequent phases. Impacts forecasted should be presented and documented relative to the baseline for the phase in which they are generated, and not casually aggregated across phases.

5. Differentiating R&D Funding Impacts. In general, it will not be apparent how to relate, in a quantitative and precise manner, the different R&D categories used to fund human factors analyses to the resulting impacts on the system design. To the extent that the R&D budget categories and the type of R&D activity are defined and applied in a consistent manner, then a degree of differentiation will be feasible.

6. System vs. Non-System Specific Impacts. In general, it will not be apparent how to estimate in a rigorous way the impacts of human factors research beyond a specific weapon system setting--that is, to classes of equipment, or to general military procedures. This is particularly true for "basic" research. (Note: This problem could be an artifact of the budgeting procedures used in DOD. A distinction between human factors research (which is non-system specific) and human factors engineering (which is system specific) might remove the problem altogether.

7. <u>Risk and Uncertainty</u>. In general, the treatment of risk and uncertainty in models that assess impacts is not adequate. Procedures do exist to quantify and incorporate risk in cost and benefit projections. See, for example, Fisher (1973), Beers (1957), Sobel (1965), Murphy (1970), and Dienemann (1966).

8. <u>Manpower Policy</u>. Analytic techniques tend to mask the military manpower policy effects on candidate design changes generated by R&D results or design variations. In general, a simulation model is required to incorporate the impact changes and manpower policy requirements in a consistent framework. Such models are often not applicable until the later stages of the system development process.

9. <u>Rigor vs. Broad-Based Analysis</u>. A fundamental issue underlying many of the above points is whether the analysis should be primarily rigorous, and statistically complete, or primarily relevant (descriptive and broad). A rigorous evaluation requires (a) formal problem statements, (b) definition of the analysis and testing process within a communicable model framework, (c) the capacity for replication by different analysts at different times, (d) evaluation designs dependent upon the use or availability of baseline or control groups, and (e) that the number of observations and the number of model relationships are both greater than the number of test characteristics or variables of interest.

The notion of broad, relevant studies is used here to imply a broad-based analysis where the intent is to describe what has taken place or is expected, to identify the predominant issues in a certain setting, and to incorporate them. Many

relevant variables cannot be measured in a rigorous, quantifiable manner (for example, user acceptance and variations in skill-mix).

This dichotomy, although somewhat contrived, is pertinent to the definition of the cost-benefit or impact analysis. This is so because not all human factors issues or parameters can be analyzed in a rigorous manner. This limitation on rigorous analysis must be dealt with explicitly in a tradeoff decision during the formulation step of the analysis.

Dealing with the foregoing methodological limitations in itself requires management and analysis resources. It is important to recognize what the related estimated costs are for the evaluation of the impacts. If the costs of the analyses are comparable to the expected value of the impacts, then it is likely that the analysis as defined is inappropriate and a simpler approach is called for.

Redefinition of the Role of the Human Factors Practitioner

As the present project has evolved, it has become increasingly apparent that the role of HF staff engaged in major system development programs needs to be updated and clarified. As suggested in Chapter 2, such refinements are needed to ensure compliance with newly issued regulations. But there has also been a realization that a strictly formal response to the new regulations would not suffice. Rather, a review and adjustment

*The trade-offs implicit in this dichotomy have been recognized for many years and were addressed forcefully and cogently by Sinaiko and Belden in 1963.

is needed that also makes explicit the observation that the HF staff has a dual function, both parts of which change as each new stage of system development is reached.

One part of the dual function is strictly technical, in the sense that it focuses on the design of the system. In this role the HF staff member is obliged to contribute technical advice on specific decisions. This role is more or less well-delineated in the literature and traditions of human factors, and is also reflected in the wording of the new regulations.

The second role, however, is rarely addressed explicitly in either the documentation of system development or in the texts that cover HF as a discipline. This second role is the support of the coherence and credibility of the system development program as a whole. In other words, we are suggesting that the HF staff members accept a significant part of the responsibility for sustaining the viability of any system development program to which they are assigned in a professional capacity. The HF professional must contribute his technical knowledge and expertise to the PM, as well as understand the problems and perspectives of the other disciplines on the PM's staff.

The Focus Provided by the Principal Product

Our effort in deriving the principal product notion has made clear the fact that human factors should be conducted by an HF staff having a broad understanding of both the systems acquisition cycle, as outlined in DOD directives, and the acquisition process in actual practice. Each development phase has its various task forces, agencies, objectives, and evaluation committees associated with it. In order to ensure that human factors has maximum impact upon the development of a system, HF personnel must be able to influence those parties who make critical decisions during the development cycle.

When HF expertise contributes to such decisions, the resultant human factors requirements have a positive and cumulative effect upon the remaining developmental phases. Given that the human factors engineer does understand the system acquisition process and touches base with the appropriate participants, he needs evidence of his past and potential contributions. Although the principal product represents a process, this process should yield a "product," that product being tangible documentation of the HF contribution.

It has been stressed that an HF principal product is (or should be) one of the key documents at each milestone in the review sequence. Thus, in a broad sense, the principal product has some of the features of a progress report, some of the features of an historical record, and some of the features of a promotional presentation. Insofar as each milestone review can determine the fate of the system/program, the HF principal product can be analogous to a lawyer's brief--a kind of synoptic argument in favor of a continuation of the development activity.

In this context, the generic function of the HF principal product can be denoted as follows:

- Support for the viability of the system/program.
- Support for the specific design decisions.
- Support for the continuation of the HF role within the total program.

These functions are highly interrelated. As we have seen in the preceding discussion, the continuation of the investment in an HF presence (staff) can be contingent upon the demonstration that the design decisions recommended by the HF staff have a positive payoff in terms of reduced costs or enhanced effectiveness, or both. Thus, if the design decisions can be justified objectively

and unequivocally, the justification of the HF role is virtually automatic. Similarly, if the design decisions are demonstrably constructive, the viability of the total program is automatically enhanced.

Implications for the Conduct of Human Factors R&D

At present the HF role in systems development typically is limited to research done in response to basic human engineering questions and to the technical application of HF skills to specific design considerations. While these contributions are important, systems developers often perceive them as simply a means of tidying up a system after its configuration and basic design are already fixed. HF staffs should not wait to be consulted; they have to be action-oriented, "selling themselves" as real contributers.

The most difficult problem HF personnel have is that of inserting themselves into the development process in the Mission Analysis phase before a system is officially approved by the DOD. Although DOD documentation requires human factors participation in all phases of the acquisition cycle, systems initiatives may begin in any number of organizations, and there exists no machinery to ensure early human factors participation. If HF staffs are to influence the direction of system concepts such that human performance considerations will be built into basic system configuration and design, their ability to make real contributions must be known. A rapport between HF people and systems developers, combat developers, etc., should be cultivated so that those who initiate systems will seek help from the HF community at the earliest possible moment. The human factors practitioner can be invaluable in presenting "lessons learned" from predecessor systems, applicable research findings which

bear upon the system concept, and the known impacts of alternative design options. These considerations can then can be incorporated into official documents, such as the ROC and MENS.

Once the MENS is approved, two significant events occur in sequence: (a) the PM is selected, and (b) the prime contractor is chosen. Whether or not the HF practitioner has a role in this selection process, his nontechnical function should now be that of directly supporting the PM. He should make clear the value of various functional and design alternatives, assuring the PM that good human factors not only will provide a form of insurance against major failure but also will increase the chances of a highly successful system. He should also monitor as closely the HF performance of the prime contractor and interpret human factors data, whatever its source, to the PM in order that it can be acted upon intelligently. Finally, the HF practitioner should help to interpret the system to those who are outside the program staff but who can control, in one way or another, the fate of the system. In particular, this function requires the HF staff member to make a special contribution to the milestone reviews (e.g., DSARCs) and, in some instances, to actually present "evidence" at such reviews.

Recommendations

There are three substantive actions which would vastly improve the current state of the art in HF utilization, analysis, and evaluation in military system development. These actions are based in part on the case study experiences, and in part on the overall study results.

1. Handbooks are required that contain:

   - Guidance for the preparation of HF principal products and the application of the impact assessment methodology.

- Data and reference information on cost and planning factors for personnel and selected reference systems that are pertinent to HF analyses. Also, an impact metric vocabulary would be included.
- Models and their documentation for use in impact assessments. Selection criteria and application references should also be included.
- Case Examples of both the HF principal products and impact assessments with references for follow-up inquiries to the particular practitioners.

Two handbooks are recommended: one that focuses on the system developer and management community task of defining and reviewing the context of HF principal products and impact assessments; and a second that focuses on the analyst who prepares the HF principal product and impact assessment. Both handbooks would have a common goal of ensuring that the HF inputs would be relevant to and incorporated into the system development process.

The handbooks should be designed in such a way as to permit easy updates and additions on a periodic basis.

2. A Policy of Aggressive Participation on the part of human factors centers of expertise to support instruction programs, and actual preparation of HF principal products and impact assessments. The latter should take place where the major system project offices are located.

3. An Information System to collect, store, and retrieve HF principal products and impact assessments and their input data. This information system should represent

all important or HF-sensitive functions in the military and permit flexible retrieval of HF study data in a timely and convenient manner.

Summary

The primary supposition of this project has been that human factors engineers need to objectively demonstrate their accomplishments in the development of military systems. This is necessary if system developers are to perceive HF as a discipline which offers a substantial contribution. The Phase I report presented the rationale for the inclusion of HF in systems development. The main elements of that report were as follows: examples of HF deficiencies/contributions; an analysis of the acquisition cycle; and the concept of human factors in systems development.

The objective of the present (Phase II) effort has been to demonstrate the human factors principal product concept and the impact analysis framework (PPIAF) approach by the use of case studies. This proved to be an illuminating endeavor. An attempt to retrospectively assemble a principal product led to a number of conclusions: (1) HF efforts require more careful documentation; (2) Mission Analysis principal products are the most crucial but least likely to be developed; (3) since system development often does not directly follow the designated DOD guidelines, the principal products of reference systems are an important consideration; (4) an organizational system-by-HF issue taxonomy and related data bank are needed if the HF community is to take a more active role in gaining influence among the organizations and personnel who dictate the course of system development. In regard to the demonstration of impact analysis as a tool for measuring the contributions of HF, both disadvantages and advantages of the

method emerged. Data are often inadequate, and there are language gaps between engineers and HF practitioners. However, impact analysis provides both a framework for comparing and selecting HF alternatives and a discipline for identifying relevant human factors issues. In addition, it permits human factors to be represented as a parameter in the systems acquisition cycle.

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APPENDIX A

CASE STUDY INVESTIGATIONS OF PRINCIPAL PRODUCTS AND IMPACT ANALYSES

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CASE STUDY INVESTIGATIONS OF
PRINCIPAL PRODUCTS AND IMPACT ANALYSES

The case study approach both provides a base for the impact analyses and conveys a sense of what actual principal products will look like when assembled during the course of system development. The approach allows researchers to insert themselves into a position resembling that of the HF staff. This in turn provides a realistic perspective from which to view the problems of tracking the human factors effort to assemble a principal product. A case study also makes available specific information about costs, deficiencies, and fixes. This information can be weighed to make choices among various system characteristics that will be appropriate in the demonstration of impact analysis. In addition, the implementation of the methodology within the framework of an actual system enhances credibility. Finally, the case study approach helps to elucidate the problems of implementing a precise methodology in a situation in which human factors impacts have usually been evaluated subjectively.

A few additional comments are appropriate at this point. In attempting to apply this methodology to systems that were already well into development, several problems became apparent. The most significant problem was the fact that the case study systems had <u>not</u> been developed according to the approach described in the Phase I report. This meant that human factors engineering personnel were not necessarily able to participate as suggested by our approach; and, it also meant that the data required for developing the principal products were not necessarily generated. Consequently, the principal products could not be created for the

case studies according to the requirements specified in the Phase I report. Limited availability of data was a principal constraint on the impact analysis, necessitating certain assumptions when data gaps existed.

The Case Studies

Prior to the case presentations, a few comments about the case descriptions, derivation of principal products, and methodology are appropriate.

Case Descriptions

The case system selected are the F/A-18 (Navy) and SIGMA (Army). Because SIGMA (a maneuver control system) is still in a very early stage of development, the HF issue chosen for demonstrating the methodology is relevant to the Milestone 0 decision point. Thus, the system described is actually a generic computerized system for maneuver control. That is, the Mission Analysis questions pertaining to threat, reference system, role of man, etc., essentially apply to any automated maneuver control system at this point in time.

Principal Products

In the Maneuver Control case study, the principal product was patterned after the Role-of-Man Statement described in Chapter 2. This was appropriate because the Milestone 0 phase is being addressed in that case study. In the F/A-18 case study, the methodology is applied to HF actions, decisions, and issues arising during the Milestone II phase; the principal product embodies the Task Analysis and Human Engineering Requirements discussed in Chapter 2. In neither case should the principal product be considered complete. It has become clear during the

course of the project that the derivation of a principal product by an HF staff during system development is a major job; doing so retrospectively is infinitely more difficult. Stated differently, the basic problem addressed by this report has become manifest in the derivation of principal products from available documentation. Thus, the products illustrated in the report are limited examples of those which a systems HF staff should be consolidating and documenting as development progresses, and the content of the products does not match the ideal requirements delineated in the Phase I report. Finally, the choice of Milestones 0 and II products reflects an increasing awareness of the need for early HF inputs in systems development. From a human engineering standpoint, the human performance failures in a system usually can be traced to the lack of HF considerations in the early conceptual stages of a system.

Methodology

The impact analysis for each case is presented next. The methodology is rigorous, but in cases where there are gaps in the data because of incomplete HF information, certain assumptions had to be made. This is appropriate since the object of this section is the demonstration of the methodology; the limited availability of some data makes the demonstration no less valid.

Case Study 1: The F/A-18 HORNET

General System Description

The F/A-18 "HORNET" is a twin engine, all-weather, light attack fighter that is intended to replace the A-7, A-4, and F-4 currently being used by the Navy and Marines. The F/A-18 Project Manager's office is located at the Naval Air Systems Command. McDonnell-Douglas is the prime contractor, and three

other major contractors are involved in the effort: Northrop (primary fuselage); Hughes (radar); and GE (engines). The aircraft, which went into full-scale development in 1976, was first flown in late 1978 and has logged over 300 flight hours. Nine pilot-production HORNETS were built from FY 1979 funding appropriations, and an additional 25 limited production aircraft were ordered for FY 1980.

The HORNET is built to deliver 17,000 pounds of ordance; its potential range should exceed 500 miles on an attack mission. It is expected to have a combat ceiling of about 50,000 feet and maximum speed of over 1.8 Mach. The HORNET's armament includes a 20mm gun and the Sparrow, Sidewinder, and Harm missiles. It can also carry other missiles and bombs, including nuclear weapons.

The F/A-18 is quite advanced in both operational and maintenance capability. Controls and displays are designed to facilitate rapid response by the pilot in high-speed combat situations. The cockpit is fully automated and reflects the "HOTAS" concept (hands on throttle and stick). Four cathode ray tubes have replaced the familiar maze of dials. Via the throttle, stick, and up-front control panel the pilot can obtain needed information by requesting the MENU and keying in the request. The information about navigation, target tracking and acquisition, stores inventory, etc., is displayed on the HUD (head-up display) or on one of the four cathode ray tubes present in the cockpit, obviating the need for the pilot to divert his eyes from the target. The radar provides excellent target definition at long range and allows for the scanning of multiple targets while locked onto others.

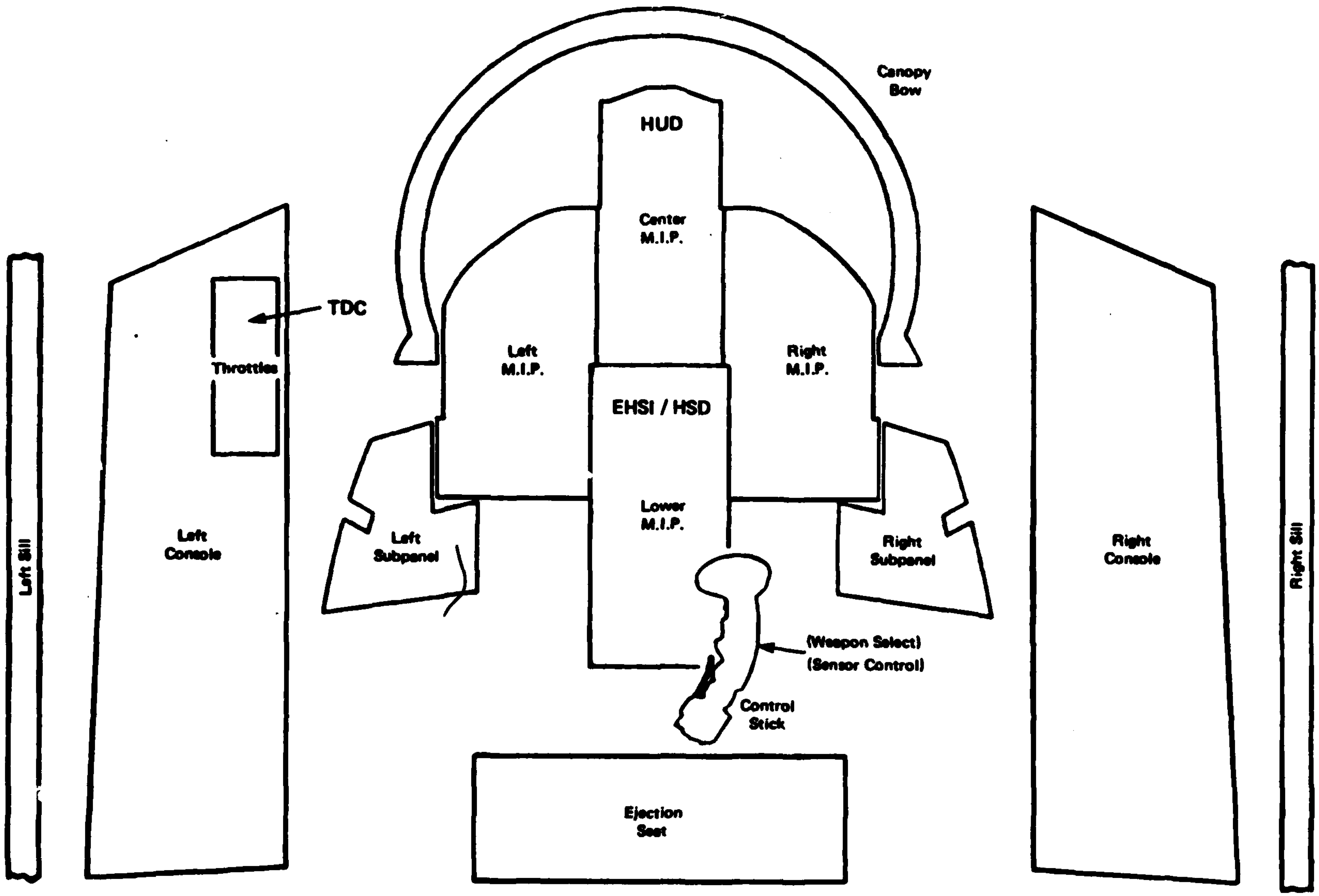
The combination of high speed (both F/A-18 and target), the requirement for instantaneous decision in combat, and the transfer

from air-to-air (a/a) combat to air-to-ground (a/g) attack led to a hardware/software design which has a substantial analysis capacity and greatly reduces the pilot's cognitive load. Many of the more critical navigational and weapon system controls and displays are located together to produce little break between strictly navigational and combat activities. For example, displayed information about weapon stores, etc. may be overridden by airspeed or angle of attack warnings. The main displays (see Exhibit A-1) contain redundant information in order to reduce the monitoring load that results from visual shifts between displays. In addition, the displays incorporate various declutter and boxing options.

The main control functions of the cockpit are broken down into three "modes" (navigational, a/a, and a/g), and the mode selected determines which weapons are activated, the parameters displayed, the appropriate displays, and the slewing of the sensors. The driving force is the HOTAS concept, referred to earlier. Response capabilities were built into the stick and throttle to allow the pilot to implement decisions instantaneously without removing his hands from either control; this also obviates the interruption of basic navigational procedures in combat. Also, various controls are built into the instrument panel to serve functions which are not usually combat related (e.g., signal analysis) and, in some cases, to allow alternatives to throttle or stick control of combat modes.

The F/A-18 system was designed to greatly reduce the cost and time of maintenance. Much of the technology is modular (e.g., radar, engines); the power plant of the F/A-18 consequently has over 7,000 fewer parts than that of the F-4. Not only are engine changes easier, but most of the parts for the

Exhibit A-1
F/A-18 Display Panels



(COURTESY OF McDONNELL-DOUGLAS)

right and left engines are interchangeable. The Navy is developing the electronic test systems required for the F/A-18 avionics and radar. These are called the Intermediate Level Avionics Support System (ILASS) and the Radar Test Station (RTS). Originally these were conceived as single-port systems, but recent analyses suggest that development of a dual-port ILASS and multi-port RTS would reduce costs and increase efficiency.

In order to reduce the amount of depot maintenance and required number of pipeline aircraft, the Navy has begun implementing Reliability Centered Maintenance (RCM). The RCM approach entails both the rating of components in terms of criticality and reliability and a reduction in the amount of "hard time" (scheduled) maintenance by the use of simpler "on-condition" maintenance tasks. Such tasks are employed to determine whether or not an item will remain in satisfactory condition until the next scheduled inspection. In general, the combination of innovative design and RCM is expected to reduce the number of component failures per hour of flying time and decrease the required number of maintenance hours and personnel. Finally, the implementation of a phased maintenance support program will give Navy maintenance personnel additional time to learn the system.

Principal Product From the Demonstration/Validation Phase

The following example of the principal product for the F/A-18 is intended to suggest the kind of format that might be employed to illustrate the HF process during the Test and Validation phase. The format represents a flexible guideline which can (and should) be tailored to the actual development process of a given system. The steps are not invariant in their

order, and they should not be considered all-inclusive. If the approach is used iteratively, it should help to provide a coherent picture of what the HF process has accomplished by the end of the developmental phase. In regard to its ultimate use, the principal product should yield a picture of the human factors decisions were, when and why they were made, and who made them. The product will effectively track the human factors effort and leave a trail of accountability. Since a variety of contractors and government agencies often play a role in the human factors aspect of systems development, this accountability is frequently absent. Also, the derivation of principal products for a number of systems could serve a broader purpose. HF profiles for various systems should illustrate where things go wrong, what distinguishes a successful from an unsuccessful effort, etc.

In the example below, the system related details were abstracted from F/A-18 documentation but do not necessarily represent either final HF decision actions or the current status of the aircraft, which is now nearing the end of Full-Scale Development. However, the presentation of actual system information should provide a glimpse of the maze of detailed information that must be pulled together to construct a principal product.

Summary of Previous Milestone Phases. A synopsis of the basic human factors products from Milestones 0 and 1 is necessary since they will have a cumulative effect and will impact the HF activities in the present phase. The products of the two earlier phases were as follows:

Milestone 0--Role of Man determined--One-man operability was decided upon for the F/A-18. Because of the multipurpose concept of the aircraft, the potential effects of a highly compact, automated cockpit upon habitability (space),

safety (ejection clearance), and operability/skill levels had to be addressed. Similarly, the effects of automation and of two sophisticated weapons subsystems on the skill level requirements of the maintenance crews had to be considered. It was decided that the impacts of the F/A-18 concept on crewstation and maintenance personnel would warrant special consideration in the human factors design effort, but that they could be dealt with effectively.

Milestone I--Allocation of Functions--The basic system functions identified in the Mission Analysis phase were evaluated for criticality, capability of the operator to perform, ability of automated equipment to perform, the impact (of functions) upon each other, time constraints, and optional ways of energizing. Thus, for example, the HOTAS concept was devised so that the time-critical transition to the a/a mode can be accomplished via the stick and throttle. Gross motor movements and changes in visual position are eliminated by the spatial consolidation of such functions as weapon selection, navigational control (air speed, attitude, etc.), and sensor slewing. On the maintenance side, some of the test functions often performed by personnel were allocated to electrical test systems.

Record of HF Activities and Actions. Human factors activities and related actions taken during designated time periods (e.g., every 6 months) should be recorded in a manner such that the HF status of the system can be clearly defined at any given time with a minimum of effort. Those items to be recorded should include design concepts documented and/or implemented; evaluations conducted; analyses performed; findings (problems encountered, issues raised, deficiencies found); and decisions

made. The record *should not be a restatement of the human engineering plan or test plan,* but a summary of those activities and actions that have had impact (real or potential) upon the operation and maintenance of the system. Recording the HF process in this way should yield a record that can be readily updated to illustrate a cumulative human factors product which is comprehensible even to those having an extremely limited knowledge of human factors engineering.

The following example is comprised of activities/actions occurring during a time "slice" of the F/A-18 Test and Validation phase. Although the events are real, their relationship in time is to some degree hypothetical. The object here is to present a tentative organizational scheme rather than a totally accurate description of the system.

Period Covered--June, _____ to Dec., _____.

A. Crew Station

A-1. Design/Document Reviews--The McDonnell-Douglas Human Engineering Crew Station Design Document illustrates the HF aspects of the basic cockpit geometry (including escape system), ingress/egress provisions, anthropometric considerations, and control/display layout and rationale. Comments on this document are included in a letter from NAVAIR (Commander) to McDonnell-Douglas dated ___________.

The following changes in the document were requested:

More information about aural tones.

Description of lighting control sensitivities.

Much clearer description of signal analysis picture.

More precise rationale for deviations from conventional control/display philosophy.

A-2. Task Analysis--The McDonell-Douglas F-18 Human Engineering Task Analysis-Part II is primarily a timeline and workload analysis. The Task Analysis Report Review conducted by NADC on ______________ included the following comments:

The concept of one-man operability was not fully demonstrated due to the undemanding requirements of the simulated mission.

The techniques used to obtain a measure of workload were not clearly demonstrated or explained.

The point at which the pilot approaches or reaches overload is not clear.

A-3. Evaluation of Escape System-Simulation--NADC Tower Tests showed contact of the foot with the instrument panel during escape. Further tests (dynamic foot strike, film analysis, instrumented foot panel, biodynamic model computer, and test sled) are anticipated in the near future.

A-4. Air Station Advisory Panel (ASAP)--Review of Naval Weapons Center Technical Memorandum ______________. The panel generally agreed with the deficiencies and fixes recommended in the memorandum with a few exceptions. This information is summarized and presented in an appendix.

B. Maintenance

B-1. Design Documents/Reviews--Critique of the McDonnell-Douglas F-18 Maintainability/Accessibility Design Document by the Commander, Pacific Missile Test Center, includes the following criticisms:

There were few informative remarks concerning accessibility, design, or potential problem areas.

The document does not meet the requirements of DID DI-H-2108 since only remove and replace tasks were covered.

Maintainability of the F/A-18 by personnel while wearing foul weather clothing was not addressed.

Yellow Sheet deficiencies were not addressed in the document.

B-2. Aft/Center Fuselage Fixture Review (Northrop)--(Source--Memo from ____________ to ____________. Problems encountered were as follows:

APU Hand Pump requires excessive time and force to pressurize accumulator.

AMAD major parts cannot be removed without removing other components.

Environmental Control System is under standard for accessibility, clearances, and values which operate in reverse of normal, etc.

Action Items

- The tests of the ejection system by NACD point to a greater than allowable probability of foot/panel contact.

Further testing and simulation should be conducted. Also, alternative designs and safety measures should be evaluated.

- Numerous inconsistencies in control/display logic observed by the ASAP need to be examined.
- The force required to operate the APU hand pump needs to be examined further.
- Maintenance time for the VSCV electrical power generator is excessive due to limited accessibility to parts within the AMAD Bay. Design alternatives related to the gearbox and fuel lines should be examined.

Important Issues. Above and beyond specific deficiencies found, certain issues are of primary importance:

- One-man operability still needs to be tested in a more demanding environment.
- Testing of maintenance tasks under adverse conditions has yet to be done.
- Aircrew task analyses have not yet clearly demonstrated aircrew workload or overload limits.
- Both the crew station and maintainability design documents are at times vague or lack sufficient detail.

The above example is intended to be just that--an example. However, its purpose should be re-emphasized. A concise, clear method of recording and updating the HF activities and status of a system is necessary if the information necessary for illustrating the costs and benefits of human factors decisions is to be obtainable.

The following example is a demonstration of how cost benefits of HF alternatives can be derived, given that the information is indeed available. In the example a few assumptions had to be made, since some of the data necessary for such analysis were not available.

Application of the Impact Assessment Methodology--F-18 Aircrew Escape System

Setting: This analysis is depicted as occurring at the Milestone II point--where the experimental prototype and the pre-production prototype designs are reviewed. The discussion and analysis will necessarily include approximations and adjustments for missing data or macrointerpretations.

Step 1: Problem Definition and Solution Criteria

Problem. Analysis of the F-18 escape system indicates a high probability of foot contact with the instrument panel during pilot ejection, and thus introduces the possibility of pilot injury.

Solution Criteria. The general goal is that any foot or skin impact be eliminated. A less stringent goal is to achieve the same probability of foot contact as for the F-18 reference systems (A-7E and F-4).

The objective of this analysis is to identify the least costly way to achieve the above goals, and to demonstrate the linkage between an HF action and a system design impact.

Step 2: Alternative Solutions

The following five alternative solutions are possible ways to deal with the foot-contact problem:

A_0 - The Baseline Design (Status Quo or "Do-Nothing" Option)

A_1 - Change the Crew Station Geometry (raise the instrument panel, lower the heelrest line)

A_2 - Crushable Energy Absorber

A_3 - Hinged Kick Panel

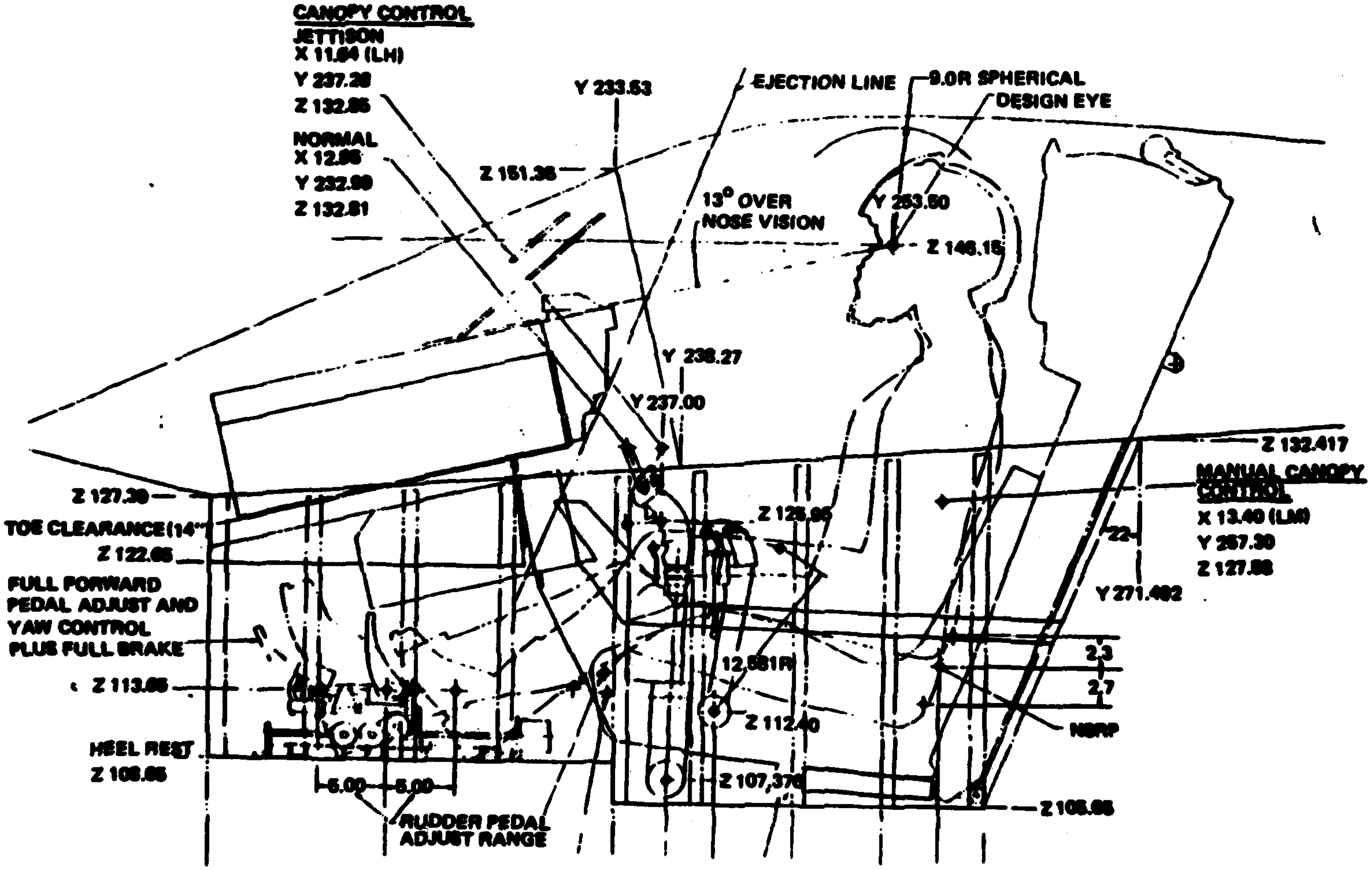
A_4 - Passive Toe Guide.

Step 3: Define the Baseline

The F/A-18 strike fighter is a twin-engine aircraft designed to meet the Navy's and Marine Corp's fighter and light attack aircraft requirements. The aircraft is planned to replace such aircraft as the A-7, A-4, and F-4, now being used for Navy and Marine Corps fighter and light attack missions such as strike escort, fleet air defense, interdiction, and close air support. The Navy also plans to develop a reconnaissance version of the aircraft to replace the RF-4 and RF-8 (GAO, 1981). The baseline is defined by the F/A-18 pre-production prototype design at the DSARC Milestone II point.

The crew station of the pre-production prototype F/A-18 (Exhibit A-2) has somewhat less toe clearance than other fighters in service. (See the System Definition Statement below.) Design requirements for the F/A-18 dictated a 14-inch toe

Exhibit A-2
F/A-18 Crew Station Geometry



(COURTESY OF McDONNELL-DOUGLAS)

clearance together with a raised heelrest line rather than the more common 16- to 18-inch dimensions. This geometry, along with a rudder pedal travel of only ±1 inch compared to ±3-4 inches in other aircraft, results in the pilot's legs being in a slightly straighter position than usual. This sitting position has increased the probability of foot contact with the instrument panel during pilot ejection.

Step 4: <u>System Definition Statement</u> (Milestone II)

For the purposes of this analysis, only portions of the typical system definition statement are needed. We have made the assumption that all data regarding Characteristics, Acquisition Policy, Deployment, Support Concept, and Logistics Goals data have been reported in the definition statement for the F-18 Life Cycle Cost or Operating and Support Cost analysis documentation (see, for example, Fabbro & Fiorello, 1977).

General	Reference System(s)		Baseline Design
A. Mission			
1. Primary: Fighter and Light Attack	Principally: A-7E and F-4J Possibly: A-4 and AV-8A		F/A-18 (Milestone II pre-production prototype)
2. Secondary: Reconnaissance	RF-4; RF-8		
B. Human Factors Issues	A-7E	F-4	F/A-18
1. Crew			
• Loading	1	2	1
• Skill Requirements	High	Medium	Multifunction fighter/attack role; high skill requirements
• Accommodations	Both craft dimensions ≥MIL-S-18471E specs		≥MIL-S-18471E except back rest of seat 1" short head rest 17° forward from back; heel-panel clearance is 14", 2" less than specs

Step 5: <u>Selection of Impact Areas and Metrics</u>

The human factors empirical findings and observations can be translated into HF system engineering metrics: crew accommodations and crew safety. Those metrics in turn can be interpreted as having primary and secondary impacts on the following system-mission areas:

Primary Impact Area: Compatibility with Aviator Population

Secondary Impacts: (a) Cost - Aviator Training
Aviator Recruiting
Aviator Retention
Aviator Injuries
Aviator Assignment Management

The alternatives identified in step 2 will be compared in terms of their relative values in the primary impact area and their respective implementation costs.

Step 6: <u>Impact Assessment Model</u>

The primary impact area, compatibility, will be defined as the percentage of the Navy aviator population that could eject from the F/A-18 with: (1) no contact, and (2) the same expected contact as for the reference systems (A-7E and F-4).

The compatibility model is defined in terms of a simple, normalized ratio of the F-18 foot-panel clearance relative to the A-7, F-4, and MIL-STD-1472B clearances over the standard deviation of selected aviator body dimension distributions. The ratio, denoted by Δ, is given in equation form below:

$$\Delta = \left[\frac{\text{Reference System Clearance} - \text{Baseline System Clearance}}{\text{Standard Deviation of the Aviator Population}}\right]$$

The ratio is in effect a multiple of the standard deviation of the aviator population, and can be used to define the percentage of the aviator population that the baseline system can accommodate relative to the selected reference system. The percentile for the F-18 will be defined relative to the 98th percentile for the reference systems. This interpretation permits a rough adjustment to the typical aviator population, so that an "average" F-18 pilot would have the equivalent foot-panel clearance as in the reference systems.

In order to explore the F-18 cockpit geometry and pilot foot-panel clearance the following techniques will be used:

1. Mock-up for static tests
2. Sled-tower testing for dynamic measures
3. Biodynamic computer simulation.

Important premises in this formulation are: (1) the lower body dimensions are correlated with foot-panel contact, and (2) the A-7 and F-4 currently accommodate the 98th percentile pilot.

For the secondary impact area, cost, the compatibility ratio, Δ, could be interpreted qualitatively into additional costs for recruiting, retention, administration, injuries, and management.

In this analysis, the alternatives will only be compared in terms of their impact on the compatibility ratio and selected other decision criteria, such as: cost to implement, complexity, and weight added to the aircraft.

Step 7: Collecting and Processing Required Data

The derivation and collection of the required data include the following steps:

1. Definition of the baseline design and the reference systems foot-panel clearance dimensions. These data are shown in Exhibit A-3.

2. Interpretation of the aviator population in terms of the means and standard deviations of selected body dimensions. These data are derived from MIL-STD-1472B, and are presented in Exhibit A-4.

3. Collection and interpretation of reference system escape occurrences stratified by selected body dimensions and foot-panel contact. These data are presented in Exhibit A-5, and indicate that there is roughly a 4:3 greater likelihood of contact upon ejection for those pilots who exceed the mean in leg length and buttock-to-knee length than for those who are shorter than the mean.

   Unfortunately, there were no data available on knee-foot dimensions and cockpit contact upon ejection. These data are not conclusive, but do indicate that there is a potential positive correlation between the knee-leg dimensions and panel contact. These observations and findings by (Lane, 1971) and (Lodge, 1963) support the hypothesis that the probability of contact and injury is positively correlated with increasing leg and buttock-to-knee lengths. Other parameters are also relevant, especially the dynamic conditions at the time of ejection, such as air speed, sink rate, attitude, and center of gravity.

4. Empirical testing and simulation analyses of the baseline design and alternative solutions were also carried out.

Exhibit A-3
Foot-Instrument Panel Clearance

System	Clearance (inches)
F-18	14
A-7E	16.75
F-4	18+
MIL-STD-1472B	16

Exhibit A-4
MIL-STD-1472B Aviator Population Dimensions

Selected Body Dimensions	Percentile Values: 5th	95th	Mean	Standard Deviation
Sitting height, erect	33.7"	38.8"	36.3"	1.55"
Knee height, sitting	19.3"	23.6"	21.5"	1.3"
Buttock-knee length	22.0"	25.8"	23.4"	1.16"
Functional leg length	40.9"	47.4"	44.15"	1.98"

Source: MIL-STD-1472B

Exhibit A-5

Data on Ejections: 1969-1977 for Navy Aircraft (1,2)

Body Component

		Contact		No Contact	
		%	QTY	%	QTY
Leg length	< Mean	50%	16	59%	223
	> Mean	50%	15	41%	155
			31		378
Buttock-knee	< Mean	30%	10	37%	138
	> Mean	70%	23	63%	235
			33		373
		Injury		No Injury	
		%	QTY	%	QTY
Sitting height	< Mean	38%	23	38%	135
	> Mean	62%	38	62%	222
			61		357

1. Data from: Shannon, Ejection Injuries from U.S. Navy Aircraft, Naval Air Station, June 1979.
2. Means from: MIL-STD-1472B data for aviators and assumption of a normal distribution.

A series of tests was carried out on the F-18 escape system including mock-ups, computer modeling, and sled-tower dynamic analysis. These tests confirmed that there is a high probability of cockpit contact for pilots when ejecting from the F-18. A Navy medical panel reviewed the test findings and could not determine conclusively whether or not contact would be injurious to the aviator, and recommended that the possibility of contact be eliminated.

A second series of tests was conducted to gather data on the various alternative solutions and assess their relative effectiveness at reducing the probability of contact. The data derived from the tests are presented in Exhibit A-6.

Exhibit A-6

Empirical Test Data on Alternative Solutions

	Alternative Solutions	Foot Clearance	Weight Impact	Implementation Complexity
1.	Redesign Crew Station	Meet specs	High	High
2.	Crushable Energy Absorber	Reduced	4 lb	Simple
3.	Hinged Kick Panel	Meet* specs	5 lb	Moderate-High
4.	Passive Toe Guide	Meet* specs	<1 lb	Simple

*Appear to eliminate the potential of contact. The toe guide provides the equivalent of increasing the foot clearance by over 4 inches.

Step 8: Setting the Conventions

For the primary impact area, the major convention used is that the aviator population is normally distributed about the mean value, and that the pilot population for the reference systems is described by that distribution.

Step 9: Estimating and Evaluating the Impacts

Based on the discussions of the baseline design and the reference systems, as well as the data analysis, the following determinations can be made:

1. The clearance ratio, Δ, takes on the following values for the reference systems indicated by the subscripts:

   $\Delta_{A-7} = 2.1$

   $\Delta_{F-4} = 3$

   $\Delta_{1472B} = 1.5$

2. Using the 98th percentile (2 standard deviations above the mean) as the upper bound of the compatible aviator population for the A-7 and F-4, the above clearance ratios equate to the following percentiles for the "equivalent" F-18 aviator population:

	Relative to the Reference System		
F/A-18 Baseline Design	Δ_{A-7}	Δ_{F-4}	Δ_{1472B}
% of F-18 Aviator Population with Equivalent Compatibility to the Reference Systems	46%	16%	70%
	(Roughly 20 to 70% compatible)		

That is, the baseline design, when compared to its reference systems and to MIL-STD-1472B, would constrain the F-18 aviator selection to somewhere between the 16th and 70th percentile. These constraints would essentially make the F-18 pilot-cockpit contact occurrence the equivalent of the reference system. If the possibility of all foot contact were to be eliminated, then not even drawing the F-18 pilots from below the 20th percentile would be successful.

For a dwindling pilot retention rate, a dwindling civilian population to draw pilots from (estimated to be decreasing at the rate of 1 percent per year between 1980 and 1995), and a Navy combat pilot shortage, the implications for recruiting, retention, and training are all negative.

Step 10: <u>Presenting the Results</u>

The results of the human factors solution to the baseline design compatibility problem are listed in Exhibit A-7. The passive toe guide is the most cost-effective solution. Further, it not only has the potential to eliminate foot contact by 100 percent in the F-18, but it can also be used on other Navy aircraft to reduce or eliminate foot contact in the rest of the fleet.

Exhibit A-7

Impact Assessment Summary

		Impact Measures			
	Alternatives	Aviator Compatibility	System Cost	Performance Weight Impact	Cost to Implement
A_0	Baseline	20 to 70%	Baseline; No change	None	None
A_1	Change Crew Station Geometry	100%	High Impact	NA	Very High
A_2	Crushable Energy Absorber	Approximately 10%	Low	4 lb	Low
A_3	Hinged Toe Guide	100%	Medium	5 lb	Medium
A_4	Passive Toe Guide	100%	Low	<1 lb	Low

Case Study 2: A Generic Tactical Operating Maneuver Control System

General System Description

The Maneuver Control System is an automated network which will assist G3/S3 (operations) in responding to critical information requirements of the commander, including the extraction of information from other functional area control systems. Specifically, it is intended to facilitate coordination between Maneuver Control and the following centers: Air Defense Artillery, Fire Support, Intelligence, and Combat Service Support. The system has been proposed in response to existing deficiencies in automated command/control systems. The system will be robust, functioning in dynamic environments, and will be designed so as to reduce information bottlenecks at the nodes of the system. The primary piece of equipment is a computer terminal that, along with the associated software, will have the following capabilities:

- Allows for the exchange of information among all echelons.
- Has a memory retention capability during power loss or fluctuation.
- Alerts operators of storage capacity approaching the limit.
- Facilitates error correction and has edit capability.
- Allows simultaneous reception/transmission.
- Allows for the reconfiguration of user terminals in five minutes.
- Provides for off-line fault detection down to the lowest replaceable unit.
- Incorporates camouflage and easy portability.

The system is conceived as a maneuver control for all echelons from Corps down to Battalion, including the following divisions: Armor, Infantry, Mechanized (AIM), Airmobile, and Airborne. At the Corps and Division level the system is to be located at both the Main Command Post and the Tactical Operations Center, and computerized terminals are to be placed in those area centers mentioned earlier (Air Defense, Fire Support, etc.).

Principal Product From the Mission Analysis Phase

The means chosen to address the principal product was to generate an (tentative) outline for a principal product that would be prepared during the first phase of major system development in the period leading up to the review process prior to Milestone 0. By and large, the outline reflected the points in the Phase I report, which delineates an ideal principal product content. Three major areas of concern are covered: operational utility, technical inputs, and management considerations including both system costs (i.e., life cycle or ownership costs) and development costs.

The first three sections of the principal product which follows can be described as brief background statements. The main purpose is to assure that the principal product document is a useful, intelligible paper on its own. While the topical coverage of these first three sections is likely to be repetitious with respect to other program documents, they can and should convey a unique human factors point of view.

The fourth section is the heart of the technical presentation and should reflect not only the design/configuration recommendations but also serve as an archival record of what the human

factors contribution was--in this phase--and how the contribution was accomplished in a technical sense.

Topic 5, the Projected Development Plan, is also crucial. It permits the HF representatives to respond to a need on the part of program management and at the same time to make the case for continuity of HF participation.

Topic 6 is pro forma. The appendices would reflect the need to be comprehensive in the explanation of the methods used to derive the conclusions asserted in the Topic 4 and Topic 5 headings.

The Maneuver Control System Milestone 0 principal product which follows is both incomplete and, in large part, hypothetical. However, it does serve as the basic input to the impact assessment application, and it is further amplified during discussion of the methodology.

<u>Principal Product Statement</u>

1. Introduction

A. Purpose

The purpose (illustrative) of this report is to review (synoptically) the development of the (hypothetical) system to date. It identifies crucial issues in the human factors area and specifies deficiencies that can be used as an analytic starting point to justify continued participation by human factors professionals in the future development of the system.

B. Logic of Approach

The format of this report is such as to ensure coverage of three areas: Military operations (i.e., requirements); technical (technological) options and constraints; and management aspects (including costs and scheduling). It is intended to serve as a source of information for high-level staff review of the system development effort and as a source of guidance to the Program Manager in his/her planning function when such a person is so designated.

2. Program Rationale

A. Operational Problem

1. Threat Environment. Warsaw Pact ground forces outnumber and outgun the NATO ground forces on the European continent. Warsaw Pact forces are upgrading their own maneuver control capability and must handle large, dispersed units in a highly coordinated manner.

2. Military Objective. NATO, and particularly U.S., ground forces must be able to redeploy and concentrate extremely rapidly if they are to be able to win in the threat situation outlined above.

B. Technological Opportunity

Computer technology, particularly microminiaturization and liquid crystal display capabilities, appears to provide a basis for the development of compact, rugged systems for providing crucial information quickly to tactical decision-makers.

C. Other Factors

Present force structures (corporate level and below) that provide for independent mobile rescues and independent strike, recon, anti-aircraft, engineering, and direct fire units are increasingly complex, and their control requires a multiple, horizontal network for C^2. The resultant message traffic in both directions can become very heavy.

3. Predecessor System

A. Base Case Deficiencies

1. General. The present system is manual and hierarchical. Its data storage (memory) and information retrieval capabilities are limited. Adding more personnel (i.e., headquarters staff) contributes more to the coordination load than it serves to relieve the information processing backlog in high message traffic situations.

2. HF-related. Data from exercises indicate that the delay from event occurrence to display at corporate headquarters is 8 to 10 hours, as against a requirement for a delay of less than 2 hours.

B. Upgraded Base Case Option

The only option for step-wise improvement of the present manual system would be some form of partial automation. In this case, that could mean the creation of computerized files for some kinds of information, but not for others. The likely result would be a "lowest common denominator" effect whereby the delays would be driven by the slowest component and the net outcome would be no improvement.

4. New System Design Concept

A. Overall Configuration

The basic concept is that of an intelligent terminal. The essential functions include communication, information processing, storage, and display. The system is portable and rugged. It can be used with minor peripheral alterations from the Battalion level on up.

B. Role of Man

1. Crew/Complement Composition. The system requires a single operator at the E-5 to E-6 level.

2. Basic Assignments by Position. N/A

3. Summary Rationale. The configuration is essentially a military adaptation of an advanced commercial version of an intelligent terminal. Thus, while many of the hardware components are of very recent vintage, they are not state-of-the-art in the usual sense because they have commercial counterparts that are off-the-shelf items. On this basis, the initial configuration of displays and controls (i.e., the keyboard) and the operating procedures are derived from commercial practice and adapted to the military mission.

5. Projected Development Plan

A. Technical Goals and Objectives

The immediate target is to reduce operator errors to a minimum and to speed up display generation or regeneration, as data uptake takes place in real time.

B. Problem to be Overcome

The prototype concept involves the use of complex instructional codes (i.e., computer commands) and keying procedures that are far from self-evident. This means that operators must be highly trained in this specific system and, in case of battle casualties, operator replacement could be impossible.

C. Approach

The approach suggested is to re-evaluate both the keyboard configuration and the procedures of use. It is recognized that to reduce the complexity of the procedures, the software could become more elaborate and voluminous.

1. Tasks.

a. Man-machine function analysis.

b. Cost-effectiveness tradeoff analysis.

2. Staffing. Six professional-level person-months will be needed to arrive at a definitive design recommendation regarding the optimum balance between the complexity burden on the human operator versus the complexity of the software plus reconfiguration of the prototype keyboard.

6. Summary and Conclusions (outline only included here)

A. Need (for the system)

B. Conceptual Response

C. Prospects--Implications of Next Developmental Phases

Appendix 1: Role of Man Analysis

A. Mission Function

B. Options

C. Procedures Used to Evaluate Options

D. Conclusions.

Appendix 2: HF Staffing Recommendations

A. Concept Development Phase

1. Major design issues
2. Cost envelope
3. Effectiveness considerations
4. Method of integration (impact analysis)
5. Quantitative conclusions.

B. Demonstration/Validation Phase

1. Approximations

C. Full Scale Development Phase

1. Approximations

Application of the Impact Assessment Methodology: Tactical Operating Maneuver Control System

Setting: This analysis focuses on the human factors (HF)-related issues identified in the HF principal product for the Milestone 0 decision. The Milestone 0 scope of the HF principal product for C^3 systems includes Role of Man, Function Allocation, and Task Definition considerations for both operation and support aspects of the mission.

Step 1: Problems, Goals, Criteria

Problems - The HF principal product analysis has identified the non-dedicated user (operator and field maintainer) issue as a significant HF-related problem that fundamentally impacts the system mission effectiveness and life cycle support.

The problem can be defined as the inability of a person not specially trained to operate the terminal effectively. One could not expect that even a communication technologist with extensive experience in the operation of conventional computer terminal devices would be able to make any sense out of the message codes and input procedures of the particular device in question. It is known that the exigencies of programming a computer for any particular function--especially one as complicated as maneuver control--can lead to programming solutions that "work," in the sense that the program runs, but that are awkward and often very complicated from the operator's point of view.

The basic Role-of-Man issues are: How much should the machine do? and How much should the operator do? The problem statement is how to cost-effectively trade-off computer program complexity and the complexity of the operator's job. This sort of trade-off is at the heart of the Role-of-Man analysis concept.

Goals - The goal of the fielded system is to achieve a 90% readiness for the primary mission during wartime. A lower-level goal is to permit the non-dedicated user to perform essential send-and-receive operations for the primary wartime mission of the system. A collateral lower-level goal is to achieve the above mission-related goals at an affordable life cycle cost.

Criteria - The achievement of the above goals will be determined by estimating the variable life cycle costs of a system design that meets selected benchmark tasks and non-dedicated user performance thresholds.

Step 2: Alternative Conceptual Solutions

For this illustration, only two conceptual alternatives to the reference system will be considered.

Alternative A - An extreme case of austere, system-specific computer programming. All the displayed messages are in a code and format unique to the particular system, or employ only a small set of "universal" symbols such as the map symbols used by the Army to designate categories of ground units. The keyboard is in a unique, special configuration and the input procedures are also unique. This alternative represents an austere version of the initial TOS tactical computer terminal design.

Alternative B - The extreme opposite of Alternative A, in that the computer programming is far more elaborate and permits the system to operate in a virtual natural language mode. Some abbreviations are used, but both messages and input procedures either are in plain English or employ universal symbology. Furthermore, the system is designed to be very "forgiving," in that, for example, input errors are simply noted (on the display)

and the operator is cued by the machine about how to rectify the error--as opposed to a condition wherein any input error could "jam" the program. This alternative represents an advanced design with more systems capabilities than are present on the contemporary tactical computer terminal/system.

Step 3: Define the Baseline

The baseline is the system design that exists at the beginning of the analysis. For example, in the analysis during the Milestone I phase, the baseline is the system design(s) that resulted from the Milestone 0 analysis. In the case of the Milestone 0 analysis, the baseline is often defined in terms of the existing mission-reference system. Thus, for this analysis, the baseline is represented by the present, manual Maneuver Control System. The typical operation of the manual Maneuver Control System involves voice and teletype inputs to a map plotter in the Tactical Operations Center. Delays and errors due to message overload are notorious deficiencies of the existing system. Moreover, the capability to coordinate maneuvers based on a common representation of the battle environment at all levels of command does not exist in the manual system.

The reference system does have the advantage of being able to use operator personnel whose training need not be system-specific.

Step 4: System Definition Statement

For the C^3 force level and maneuver control mission analysis of Milestone 0, only the following definition statement components are required.

Mission: Design Requirements -

a. General - To command and control tactical units, including the capability to provide survivable, reconstitutable, secure, and interoperable means for tactical force management and technical support of nuclear and general purpose force operations.

b. Timely Processing of Information -

(1) Allocation or reallocation of maneuver and fire support units within 2 hours.

(2) Carrying out of conventional situation assessment, decisionmaking, and dissemination of orders within 3 hours.

(3) Developing situation assessment products within 20 minutes at Corps and Division.

(4) Ensuring that all assessment information (friendly and enemy) is current to within 1 hour.

c. Continuity of Combat Operations -

(1) *Responsiveness*. The ability to rapidly disseminate information to all levels of command. It is characterized by the capability for having time-sensitive information available during the decisionmaking process.

(2) *Survivability/Security*. The ability of the system to deny and/or withstand enemy radio electronic combat (REC). It is characterized by the ability to minimize the effects of enemy efforts to intercept, monitor, analyze, locate, and target friendly forces, and by the ability to survive physical attack.

(3) *Dependability.* The ability to ensure that critical information is exchanged among users with minimum loss of accuracy. It is characterized by the ability to provide both a high degree of reliability, availability, and maintainability in a highly mobile tactical environment, and efficient handling of traffic loads with ranges of 750 to 1100 messages per hour.

(4) *Flexibility.* The ability to be rapidly deployed and employed to support ground combat by providing critical information. It is characterized by the capability to provide continuous information through various communications means.

(5) *Interoperability.* The capability to interact with existing and programmed information systems of ground combat used by other services, and with the command and control systems of allied nations.

Design: Operational Characteristics -

a. Display - Produce hard copy (alphanumeric/graphic) at the same scale as display. Also, large screen display; declutter, re-arrangement of symbols, etc.

b. Storage/Retrieval - Save symbols, memory retention during power loss, alert user about storage capacity approaching limits.

c. Composition - Save distribution lists for multiple addresses; minimal user action. Composition aided through prompts; valid entries for fixed formats will be pre-defined.

d. Reception/Transmission - Simultaneous reception/ transmission without interference of the message preparation; when load over peak, graceful degradation by discontinuing information flow in inverse order of priority.

e. Edit Capability/Error Detection - User can modify message without deleting or recreating the message. A communication error detection capability also will exist.

f. Keyboard/Compatibility - Keyboard designed so that user can work while wearing protective clothing.

g. User Requirements/Training - Designed to be used by those personnel meeting the requirements of the user population projected by TRADOC. TRADOC will update the Individual and Collective Training Plan (ICTD).

h. Design Life Expectancy - 10 years.

i. Fault Isolation - Provide for on/off-line fault detection down to lowest replaceable unit.

j. Data Distribution Considerations - The system must be designed to operate in the current communication environment as well as with emerging communication systems. There is no intention to develop a dedicated communications system to satisfy this need.

Acquisition/Deployment -

a. Development Costs - (TBD).

b. Procurement Costs - (TBD).

c. Deployment - Mid 1980s

- European/NATO setting/Corps, Division/Battalion, Company
- Systems will be deployed as part of existing maneuver control organization.

<u>Support Considerations</u> -

a. Compatibility -

(1) Improved capabilities must be supportable and compatible with existing and future logistic concepts. Design configurations should be appropriate to the employment environment, recognizing the requirements for system mobility for ground maneuver units, as well as life cycle costs.

(2) The system must be designed to minimize the need for high-skill personnel, and must not exceed the minimum expected skill level (prerequisite aptitude score) of maintenance and operating personnel for generically similar equipment existing in the field.

(3) Operators will perform field level (1st echelon) maintenance.

b. Training -

(1) A Training Subsystem must be developed to provide for a transfer of knowledge to the system user and maintainer. The training package must be designed to be cost effective within the limits of training constraints.

A summary comparing the reference system and the two conceptual alternatives is provided in Exhibit A-8. The major difference between the two alternatives is the man-machine distribution of the workload burden and the consequent life cycle cost and mission impacts. Both Conceptual Alternatives are expected to meet the mission specifications, principally through the introduction/utilization of off-the-shelf and state-of-the-art technologies.

Step 5: Selection of Impact Areas/Metrics/Empirical Measures

The reference system does not satisfy the current and forecasted mission requirements. The two conceptual alternatives are designed to satisfy the mission needs, but will have different cost and compatibility values. Thus, for this analysis, the formulation will be based on a fixed effectiveness threshold and variable cost and compatibility comparisons. The Impact Areas of interest are Cost and Compatibility.

Each of the Impact Areas can be defined in terms of selected metrics that provide more specific breakouts of the alternative design impacts on the current Army organizations and budget.

For the Impact Area of Cost, lower-level metrics can be selected from the Joint Tactical Communications Systems/Equipment Life Cycle Cost Model (Report TTO-ORT-032-76B-V3, Joint Tactical Communications Office (TRI-TAC); and the Army Materiel Command, Pamphlets 11-2, 11-3, and 11-4). For Milestone 0, virtually all system life cycle costs are variable, in that they have not yet been incurred and current design decisions can affect them. However, this formulation is concerned with the comparative differences between two alternatives, and only the relevant costs--that is, those that are variable between the alternatives--are needed. The selected relevant, variable costs are identified in Exhibit A-9.

Exhibit A-8
Comparison of Alternative System Concepts

	Reference System	Alternative A	Alternative B
Support Considerations			
a. Compatibility	Uses E5-E6 staff	– High operator/maintainer skill requirements; will impact manpower organizations. – Will not accommodate the non-dedicated users.	– Compatible with current system operator/maintainer skill requirements. – Will accommodate non-dedicated users for basic operations/maintenance.
b. Training	Standard training curricula	– Will impact training organization; requires new, extensive training and retraining of personnel.	– Requires a new training curriculum, but about the same duration as for current program.

Exhibit A-9
Selected Cost and Compatibility Metrics

Impact Area	Metrics: Name	Metrics: Symbol	Empirical Measure
Life Cycle Cost	Research and Development – Software Development and Hardware Design Fabrication	C_{RD}	Dollars
	Investment – Acquistion	C_{AC}	Dollars
	Operation and Support – Operators – Training – Replenishment Spares	$C_{O\&S}$	 Dollars Dollars Dollars
Compatibility	Skill Requirements	(SR)	% of current Tactical Operation Systems personnel
	Task Loading	(TL)	Ratio of relative loading

The selected metrics for the second Impact Area, Compatibility, are also listed in Exhibit A-9. The metrics for measuring compatibility include: Skill Requirements, and Functions and Task Loading.

Step 6: Construction of the Impact Assessment Model

For this Milestone 0 analysis, macro planning factor models are appropriate. The basic equations for each of the cost metrics are taken from the Army Life Cycle Cost Model and/or the TRI-TAC Tactical Communications Life Cycle Model, and are listed below.

Cost of Research and Development (C_{RD})

C_1 = Cost of Research and Development

$$= \sum_{i=1.01}^{1.10} C_i$$

where, $C_{1.01}$ = Development Engineering Cost

$C_{1.02}$ = Producibility Engineering and Planning Cost

$C_{1.03}$ = R&D Tooling Cost

$C_{1.04}$ = Prototype Manufacturing Cost (includes software development costs)

$C_{1.05}$ = R&D Data Cost

$C_{1.06}$ = R&D Test and Evaluation Cost

$C_{1.07}$ = R&D System/Project Management Cost

$C_{1.08}$ = R&D Training Services and Equipment Cost

$C_{1.09}$ = R&D Facilities Cost

$C_{1.10}$ = Other R&D Cost

Cost of Investment (C_{AC})

C_2 = Investment Cost

$$= \sum_{i=2.01}^{2.11} C_i$$

where, $C_{2.01}$ = Non-Recurring Investment Cost

$C_{2.02}$ = Production Cost

$C_{2.03}$ = Engineering Changes Cost

$C_{2.04}$ = System Test and Evaluation Cost

$C_{2.05}$ = Data Cost

$C_{2.06}$ = Production Phase System/Project Mgmt Cost

$C_{2.07}$ = Operational/Site Activation Cost

$C_{2.08}$ = Training Cost for 10 yr. Operations

$C_{2.09}$ = Initial Spares and Repair Parts Cost

$C_{2.10}$ = Transportation Cost

$C_{2.11}$ = Other Investment Cost

Cost of Operating and Support ($C_{O\&S}$)

C_3 = Cost of Operating and Support

$$= \sum_{i=3.01}^{3.06} C_i$$

where, $C_{3.01}$ = Military Personnel Cost

$C_{3.02}$ = Spare Parts Cost

$C_{3.03}$ = Depot Maintenance Cost

$C_{3.04}$ = Materiel Modifications Cost

$C_{3.05}$ = Other Direct Support Operations Cost

$C_{3.06}$ = Indirect Support Operations Cost

Many of the above cost factors will be estimated directly and based on manufacturers' or military historical data. If the factors are significant they will be computed by equations that use lower-level elements. The set of significant cost factors is: $C_{1.04}$, $C_{1.06}$, $C_{1.08}$, $C_{2.02}$, $C_{2.08}$, $C_{3.01}$, and $C_{3.02}$. Examples to illustrate this type of equation are given below.

Cost of Training

$C_{2.08}$ = Training Cost
= (TMYT)(NTMY) + (TE)(NTE) + (TSP)(TE)(NTE) + (TF)

where, TMYT = Cost per man-year of training
NTMY = Number of man-years of training
TE = Cost per training equipment set
NTE = Number of training equipment sets
TSP = Training equipment spares factor
TF = Training facilities cost

Cost of Operator Personnel

$C_{3.01}$ = Military Personnel Cost
= (N/OS)($/OP)(HYr)(QTY)

where, N/OS = No. of operators per system
$/OP = Cost of operator personnel
HYr = Operating hours/yr.
QTY = Quantity of operational equipment

Spare Parts and Replenishment Material

$C_{3.02}$ = Spare Parts Cost
= (IRCF)(EUC)(QTY)

where, IRCF = Inventory replenishment cost factor
EUC = Equipment unit cost
QTY = Quantity of operational equipment

Once the costs for each of the alternatives are computed, the difference between the two can be determined and the preferred design identified.

For the compatibility metrics, available historical test and operational data on fielded and experimental systems will be assessed and interpreted for skill requirements and task loading impacts of the two conceptual alternatives.

Step 7: <u>Collecting and Processing Required Data</u>

Nominal values for selected, significant cost elements and other driving factors are listed in Exhibit A-10. For those variables not listed, standard USA or TRI-TAC factors were assumed.

Step 8: <u>Establishing Conventions and Assumptions</u>

For the purposes of this analysis, the following conventions will be used:

- Steady state operations.
- 1980 constant dollars are used, unadjusted for inflation or for the time value of money.
- Technology and training are off-the-shelf capabilities.
- The maneuver control units will be deployed within existing organizations that currently perform that function.

Step 9: <u>Estimating and Evaluating the Impacts</u>

Using the above data and equations, the differences between Alternatives A and B for each of the cost metrics are shown in Exhibit A-11.

Exhibit A-10
Selected Cost and Resource Factors

Significant Factors (Defined in Step 6)	Nominal Values Alternative A	Alternative B
$C_{1.04}$	–	Δ(A-B) = $500,000
$C_{1.06}$	–	Δ(A-B) = $100,000
$C_{1.08}$	–	Δ(A-B) = $100,000
$C_{2.02}$ (1)	$250,000	$300,000
$C_{2.08}$		
.TMYT (2)	$ 70,000	$ 60,000
.NTMY	0.25/operator	0.10/operator
.TE	Δ(B-A) = $20,000	
.NTE	15	15
.TSP	0.20	0.20
.TF	$10,000	$10,000
$C_{3.01}$		
.N/OS	1/shift (3 shifts/system)	1/shift (3 shifts/system)
.$/OP	$18,000 (3)	$12,000 (4)
.HYL	2920 hrs./shift	2920 hrs/shift
.QTY	100	100
$C_{3.02}$		
.IRCF	0.15	0.15
.EUPC	$250,000	$300,000
.QTY	100	100
Miscellaneous Factors:		
Operator Annual Turnover Rate	40%	40%
System Operational Life	10 yr.	10 yrs.

(1) Average estimated cost over production run.

(2) Includes instructor and trainee pay and allowance plus any PCS expense adjusted for different trainee wages.

(3) Requires an Electro-Mechanical Communication-Crypto System Specialist.

(4) E-5/E-6 level operator.

Exhibit A-11

Summary of Cost Differences Between Conceptual Alternatives A and B

(All figures in contract 1980 dollars)

Cost Metric	Cost Elements	Δ(Alt. A–Alt. B)	
C_{RD}	$C_{1.04}$	< 500,000>	
	$C_{1.06}$	< 100,000>	
	$C_{1.08}$	< 100,000>	
	Others	< 150,000>	
	Sub Total$_{RD}$		<850,000>
C_{AC}	$C_{2.02}$	< 5,000,000>	
	$C_{2.06}$	16,950,000	
	Others	–	
	Sub Total$_{AC}$		11,950,000
$C_{O\&S}$	$C_{3.01}$	18,000,000	
	$C_{3.02}$	< 800,000>	
	Others	–	
	Sub Total$_{O\&S}$		17,200,000
Total 10 year life cycle cost difference			≈$ 28,000,000

Note: Figures in parentheses are negative, and totals may not add due to rounding.

Step 10: Presenting and Interpreting the Results

The expected life cycle cost for Alternative B is estimated to be about $28,000,000 (in constant 1980 dollars) less than the life cycle cost of Alternative A. This is the Δ cost impact attributable to the investment in human factors-related design changes that distinguishes concept B from concept A. The principal savings are in people-related categories: Concept B requires less training and can accommodate a lower-skilled and -paid operator. The expected investment in the human factors analysis and design changes is less than $1,000,000, which yields a return on investment of 28:1.

In addition to the cost savings, concept B provides a capability beyond that of concept A: It can accommodate a less skilled (non-dedicated) user for the essential maneuver control operations the system is to support. That pays off in increased compatibility and also increases the operational readiness of the system during combat environments.

APPENDIX B

OUTLINE AND BOOK PLAN:
HF HANDBOOK AND HF GUIDEBOOK

- **B-1:** **An Outline and Book Plan for "A Human Factors Handbook for System Developers"**

- **B-2:** **An Outline and Book Plan for "A Guidebook for Human Factors Participants in Major Military System Development Programs"**

APPENDIX B-1
AN OUTLINE AND BOOK PLAN FOR A HUMAN FACTORS HANDBOOK FOR SYSTEM DEVELOPERS

1. Introduction

The outline presented below has several special features. First, it is rendered in modified story-board format. Second, while we recognize the tri-service involvement in the project, the terminology and conceptual model of military system development have been derived primarily from the practices of the U.S. Army. This was done for the sake of simplicity and convenience, and because the preparers were more familiar with current Army practices. It is hoped that the review process will reveal where the wording or the concepts must be changed to ensure that what is being said is valid for all branches of the Armed Forces.

2. General Instructions to Authors, Editors, and Illustrators

The anticipated primary mode of use for the Handbook is as an on-the-job source of reference. This mode of use implies several requirements. First, each unit of information or section of text should be interpretable by itself. The user should not be expected to have to read long narrative passages in order to understand the essence of each particular guide to a course of action. Secondly, the Handbook should contain an index to facilitate subject look-up.

In addition to its use as a reference source, however, it will probably also be used as a general orientation tool. This means that some background and general explanatory text must be provided.

To satisfy these two purposes, a subtle shift in style and format should be introduced about midway through the Handbook. This shift might be described as a transition from the conceptual level of discourse (covering the orientation purpose) to the technical level (covering the action-guiding purpose).

The readership or audience will, we hope, be composed of professional military personnel at company-grade rank and above, civilian manager/engineer people in government service at or above the GS-13 level, and contractor personnel at the level of sub-project team leaders and above. Most audience members can be expected to have educational or experiential backgrounds equivalent to an undergraduate degree in engineering, at a minimum. Vocabulary and reading skills should therefore not be a major constraint, but authors and editors should strive to avoid jargon that is derived predominantly from the social or behavioral sciences or even from human factors engineering as a specialty.

We can expect that the general attitude or predisposition on the part of prospective readers will be neutral or indifferent. In other words, for most prospective users, the external incentives to read the material will be relatively weak. This means that some extra care should be given to the "attractiveness" of the Handbook. To this end it is suggested that physical specifications be slightly unconventional.

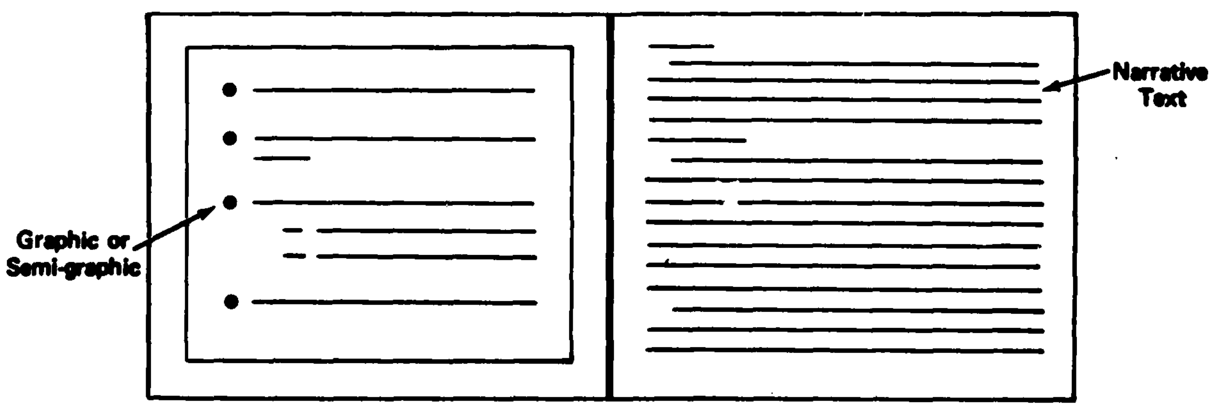
- page stock: 8½" x 11"
- binding open for discussion
- graphic (line drawing) on cover
- cover stock distinctive color, medium-heavy stock with rough (pebble) finish

- selected passages emphasized by use of a second ink or bolder/larger font
- sections separated by lightweight stock in a color that is coordinated with the cover color.

Along these same lines, the narrative style should be technical but relatively informal. Reasonable models would be *Science 81*; the Smithsonian's *Natural History*; or the popular MIT alumni periodical, *Technology Review*. These periodicals are also apt models for the use of graphics, providing as they do a mix of straight technical with more evocative items.

The format of the Handbook, as in the following outline, should be a modified story board. That is, a diagram or "bulleted" set of summary statements presented on the left page, with the narrative explanation on the right (facing) page. Substantial white space will be unavoidable on the left pages, but liberal use of white space should also be a feature of the right pages.

The layout, then, would have the following basic appearance:



3. Topical Outline

Introduction

(Note: Each topic heading will be printed across two facing pages.)

- The purpose and objectives of the Handbook
- Who should read the Handbook
- Why the Handbook should be read

(Note: Additional front-matter is described under "4. Pagination.")

Section 1: Background

- What is human factors engineering
- Historic contribution to military systems development
- Applications in nonmilitary areas
- What the human factors specialist is trying to accomplish
- How the human factors specialist does his or her job
- The research side of human factors work
- Links to other disciplines and engineering sub-fields
- Some successful instances of human factors work
- What can happen if human factors are ignored
- Costs vs. payoffs
- Limitations

Section 2: Managing the Human Factors Resource

- Where human factors specialists come from: Recruitment
- What human factors specialists should know: Technical Content
- What human factors specialists can know: Collateral Knowledge

- What human factors specialists should know how to do: Technical Skills
- The manner in which the human factors specialist contributes.

<u>Section 3: Specific Contributions of the Human Factors Practitioner</u>

- Administrative aspects of the human factors contribution:
  - Major steps and decision points (OMB Circular No. A-109)
  - Revised DOD directives (5000 Series)
  - Other policy guides
  - Military Standards and Specifications.
- The principal products of the human factors specialist's work:
  - Mission Analysis Phase Human Factors:

    Human factors efforts and system development activities during mission analysis

    Content of the Role of Man statement
  - Concept Development Phase Human Factors:

    Human factors efforts and system development activities during concept development

    Content of the Allocation of Functions to Man statement as part of the Decision Coordinating Paper
  - Demonstration/Validation Phase Human Factors:

    Human factors efforts and system development activities during demonstration/validation

    Content of the Task Analysis and Human Engineering Requirements Product

- Full-Scale Development Phase Human Factors:

  Human Factors efforts and system development activities during full-scale development

  Content of the Optimal Man-Machine Interface Design

- Production and Deployment Phase Human Factors:

  Human Factors efforts and system development activities during production and deployment

- Other potential contributions:
  - Relevant findings from basic research
  - Statistical design for system test and evaluation.

Section 4: The Evaluation of the Human Factors Contribution

- General criteria
- Quantitative analysis: Benefit-cost approach and impact analysis
- Projective evaluation: Planning your investment strategy
- Comparative evaluation: Relationship to other sources of contribution
- Retrospective evaluation: The value of the human factors cure
- Feedback: Increasing value with use.

Section 5: Rules of the Game

- Strategic considerations
- Tactical considerations
- Avoidable penalties
- Prizes to the winners.

Appendices

A. Case study of a system with a wide range of human factors design deficiencies: The Hagen automatic propulsion system

B. Hypothetical case study of the projective type: An Army C^3I system

C. Hypothetical case study of the retrospective type: The F/A-18 pilot ejection system

D. Procedures for conducting an impact analysis study.

(Note: These latter components will be in straight narrative format, augmented by illustrations included in the text. That is, there is a shift here out of the modified story-board format into conventional technical report format. Also, note that Appendices B, C, & D are included in the present report in preliminary versions.)

4. Pagination

Front cover	-	Colored stock. From top to bottom: drawing; title (in 18 pt. bold type); five logos
Inside cover	-	Blank
Unnumbered 1st rt. page	-	Title page: report number, title, authors, date, sponsor, contract number
Unnumbered 1st lft. page	-	Abstract
Unnumbered 2nd rt. page	-	Reproduction of letter or memo of authorization

Unnumbered 2nd lft. page	-	Blank
Unnumbered 3rd rt. page	-	On colored stock: "PREFACE," centered
Unnumbered 3rd lft. page	-	Blank
Unnumbered 4th rt. page	-	Same drawing as on cover
p. 1, lft. page	-	Semi-graphical: Purpose and Objectives of the Handbook
p. 2, rt. page	-	Narrative; same title as above
p. 3, lft. page	-	Semi-graphical: Who Should Read the Handbook
p. 4, rt. page	-	Narrative; same title as above
p. 5, lft. page	-	Semi-graphical: Why the Handbook Should Be Read
p. 6, rt. page	-	Narrative; same title as above
p. 7, lft. page	-	Blank
Unnumbered rt. page	-	"SECTION 1: BACKGROUND," centered
Unnumbered lft. page	-	Blank
p. 8, rt. page	-	Brief narrative summary
p. 9, lft. page	-	Semi-graphical
p. 10, rt. page	-	Narrative
(Continues to p. 30)		
p. 31 lft. page	-	Blank
Unnumbered rt. page	-	On colored stock: "SECTION 2: MANAGING THE HUMAN FACTORS RESOURCE," centered
Unnumbered lft. page	-	Blank

p. 32, rt. page	-	Brief narrative summary
p. 33, lft. page	-	Semi-graphical
p. 34, rt. page	-	Narrative
(Continues to p. 58)		
p. 59, lft. page	-	Blank
Unnumbered rt. page	-	On colored stock: "SECTION 3: THE EVALUATION OF THE HUMAN FACTORS CONTRIBUTION," centered
Unnumbered lft. page	-	Blank
p. 60, rt. page	-	Brief narrative summary
p. 61, lft. page	-	Semi-graphical
p. 62, rt. page	-	Narrative
(Continued to p. 72)		
p. 73, lft. page	-	Blank
Unnumbered rt. page	-	On colored stock: "SECTION 4: RULES OF THE GAME," centered
Unnumbered lft. page	-	Blank
p. 74, rt. page	-	Brief narrative summary
p. 75, lft. page	-	Semi-graphical
p. 76, rt. page	-	Narrative
(Continued to p. 82)		
p. 83, lft. page	-	Blank
Unnumbered rt. page	-	On colored stock: "APPENDICES," centered
Unnumbered lft. page	-	Blank
p. 84, rt. page	-	Begin Appendix A narrative

(Note: The appendices should be in two-column format. Each new appendix begins on a right-hand page, with its designation and title centered at top. The total number of pages required for appendix material cannot be specified at this time, but could run about 30-40, printed on both sides.)

(Note: The index should be separated from the appendices by the colored stock used to demarcate each new section throughout--i.e., the treatment should remain consistent. The index could require about 2-4 pages of two-column text.)

Back cover - No special treatment: blank on both sides.

APPENDIX B-2
AN OUTLINE AND BOOK PLAN FOR
"A GUIDEBOOK FOR HUMAN FACTORS PARTICIPANTS
IN MAJOR MILITARY SYSTEM DEVELOPMENT PROGRAMS"

1. Introduction

The document outlined below will be a relatively conventional representative of its genre. There is a fair-sized family of handbooks and guidebooks in the human factors area. There are also textbooks on human factors work that have a substantial weight of "how-to-do-it" content. Comparisons reveal that variations in format and style within this extended genre are marginal.

The main differences between the present document and the others in the field will be in purpose and content. The purpose of the ordinary human factors handbook is to inform the reader with respect to technical substance (e.g., anthropometric data) and technical process (e.g., how to conduct a task analysis). The intent is to improve the technical quality of the product of the human factors specialist's work (in his or her role as a technician).

The present document, by contrast, is intended to provide information that will help the human factors worker ensure that his or her product is actually used in a constructive manner. The content is oriented toward such matters as the overall nature of the process, in which the human factors work is but one part; the organizational setting; the mechanisms by which his/her participation in the process is initiated; and, most particularly, how the human factors contribution to the total process can be evaluated in a relatively rigorous fashion either by the human factors specialist or by the manager(s) of the total process.

To use a military analogy, most human factors handbooks do the equivalent of telling a soldier what a rifle is, and how to

load it, aim it, and fire it accurately at a target. The present document is more equivalent to telling the soldier how to survive and win on the field of battle.

2. General Instructions to Authors, Editors and Illustrators

The modes of use of the document being planned will probably be of two kinds, in roughly equal proportions: as a source of general orientation; and as a reference document. The situation in which the orientation function will predominate is one in which a relatively junior-level specialist is about to take up his/her first position as a member of a system planning or system development team. Similar needs will be present when a person who has worked primarily as a researcher or research manager is reassigned to development work, or when a practitioner returns to development work subsequent to a lengthy tenure as a teacher, researcher, or administrator.

The document will serve as a reference resource for those in the midst of development work, and possibly, to a modest extent, for co-workers from other, non-human factors technical backgrounds.

Fulfilling the orientation function will mean that the first sections or chapters in the Guidebook will need to have the properties of logical flow, continuity, and high readability. The more specific technical materials in the later sections of the Guidebook will need to have the properties of explicitness, fineness of detail, and comprehensiveness to fulfill the reference function. Also, as in the Handbook (Appendix B-1), a good index is essential for meeting the reference function.

The audience for the Guidebook will consist predominantly of human factors professionals. Their educational backgrounds

will be uniformly at the first postgraduate degree (e.g., M.S.) or beyond in the behavioral or biological sciences, with an admixture of a few individuals from engineering and a few from the collateral social sciences. Consequently, reading comprehension should not be a limiting factor, nor should vocabulary control be a significant problem.

The Guidebook should have a good level of reader "pull" because of its inherent high degree of vocational relevance. This does not imply that stylistic standards can be relaxed, but it does mean that the format can be unspectactular, and consequently more economical with respect to cost of production.

The style level, in fact, should probably be at the college textbook level. A good model would be *Scientific American* or the *Bulletin of the Atomic Scientist* from the field of commercial periodicals (as opposed to professional or scholarly journals).

The physical form might be that of a ring bound (i.e., looseleaf) technical report because there is a strong possibility that the Guidebook will need to be updated or augmented, or both, over the span of its intended use-life.

3. Topical Outline

(Note 1: Front matter is described in "3. Pagination")

(Note 2: The book as a whole can be divided into three major sections. Each section will contain several chapters, but each chapter should be relatively concise, averaging about 4-5 pages in length, with no chapter longer than about 10 pages. The chapters would be "replaceable units" for updating purposes.)

Section I: Orientation

Chapter 1. Overview
- purpose
- substance
- layout

Chapter 2. Steps in the standard military system acquisition process
- mission analysis
- concept development
- configuration
- test and revision
- production and delivery

Chapter 3. Exceptions and variations in the system acquisition process
- administrative
- budgetary
- branch-of-service linked
- technology driven
- situational/idiosyncratic

Chapter 4. The charter documents for human factors participation in military system development
- directives
- MIL-SPECS
- policy papers
- other (occasional) documents

Chapter 5. General roles and functions involved in the human factors contribution
- technology base
- planning
- user representation
- program justification

Chapter 6. Variations related to type-of-system

- vehicular
- ordnance
- C^2 & C^3I
- etc.

Section II: Working Methods

Chapter 7. Specific contributions; human factors principal products

-
-
-
-

Chapter 8. Pitfalls

-
-
-
-

Chapter 9. General expectations of team leaders

- combat developers
- material developers
- prime contractor - project directors
- subcontractors

Chapter 10. Specific expectations of team leaders

-
-
-
-

Chapter 11. Integration: roles, functions, and products

-
-
-
-

Section III: Assessment Methods

Chapter 12. Evaluation operations

- general-subjective
- technical-objective
- principles of benefit-cost analysis

Chapter 13. Team leader-initiated evaluations

- instigation: projective and retrospective
- procedure
- interpretation of findings

Chapter 14. Self-initiated evaluations

-
-
-

Chapter 15. Impact analysis methodology

-
-
-
-

Chapter 16. Alternative methodologies

-
-
-
-

Section IV: Summary of action steps

Chapter 17. Getting on board

Chapter 18. Doing the job

Chapter 19. Proving worth

4. Pagination

Front cover	-	Heavy, light-colored cover stock. No illustration; contains report number, title, and organization logos.
Inside cover	-	Blank
unnumbered rt.-hand page	-	Title page: report number, title, authors, date, sponsor, contract number
unnumbered lft.-hand page	-	Blank
p. iii (rt. page)	-	Foreword: brief background; administrative remarks; acknowledgements, if any
p. iv (lft. page)	-	Blank
unnumbered rt.-hand page	-	On colored stock: "SECTION I: ORIENTATION," centered
unnumbered lft.-hand page	-	Blank
p. 1-1 (rt. page)	-	Chapter 1 title and text
p. 1-2 (lft. page)	-	Text continues
(continues to end of chapter)		
p. 2-1 (rt. page)	-	Chapter 2 title and text
p. 2-2 (lft. page)	-	Text continues
(continues to end of chapter)		
unnumbered rt.-hand page	-	On colored stock: "SECTION II: WORKING METHODS," centered

unnumbered lft.-hand page	-	Blank
p. 7-1 (rt. page)	-	Chapter 7 title and text

(Note: Chapters follow in sequence, with each chapter beginning on a right-hand page and pages numbered sequentially within each chapter.)

(Note: Sections follow in sequence, with each section demarcated by a colored, unnumbered overleaf page bearing the section number and title on its front, or right-hand, side)

(Note: Following Section IV, Chapter 19, an index to the Guidebook is provided. This section should also have an overleaf page on colored stock; the index itself will be two-column, running 2-4 pages.)

Back cover	-	Blank on both sides

APPENDIX C

PRINCIPAL PRODUCTS: ASSUMPTIONS AND ACTIONS

APPENDIX C

PRINCIPAL PRODUCTS: ASSUMPTIONS AND ACTIONS

Content of the Role-of-Man Statement

A statement of the role of man as part of the Mission Element Needs Statement (MENS) should include the following considerations:

Assumptions:

- A separate "role of man" analysis will be provided for each alternative system concept selected.
- Human engineers will develop "role of man" concepts and interact with mission analysis team in development of MENS.
- "Role of man" components are listed according to probable order of presentation in MENS (not according to their development sequence).

Actions:

1. List effects envisioned for overall system as a result of role of man devised for each alternative system concept as configured (e.g., operability, maintainability, mission effectiveness).
2. List effects envisioned for man's role/personnel subsystem as a consequence of each alternative system concept as proposed (e.g., safety, habitability, user acceptance).
3. Determine location of man in system to perform designated role.
4. Specify advantages accorded man's role for each alternative concept (e.g., facilitate operation of system, allow for contingencies).

5. Specify disadvantages accorded man's role for each alternative concept (e.g., manpower reserves consumption, level of training requirements).

6. Determine required human performance, behaviors, capabilities, and performance limits (e.g., sensing, processing, information storage, decision making, responding) identified for each functional category.

7. Determine personnel constraints impacting man's role for each alternative system concept such as the following:

   a. maximum and minimum numbers of personnel who can be used in the system

   b. types of personnel (e.g., skill level and aptitude) available for system assignment

   c. anthropometry of identified personnel population (existing and projected)

   d. user acceptance problems projected and their effects

   e. effects of system and mission as configured on personnel vulnerability (e.g., environmental hazards)

   f. communication requirements and limits (system and other personnel).

8. Determine implications envisioned for each alternative system concept upon requirements for:

   a. training (e.g., level of training, trainability, training support and facilities, training devices)

   b. manpower (e.g., manpower levels, performance availability)

   c. life support

   d. "-ilities" support (e.g., logistics, reliability, maintainability)

e. social/organizational impact (e.g., MX basing).

9. Select contributions to function analysis in Mission Analysis Phase:

   a. identification of threat

   b. need demonstration: new system or modification to current system

   c. requirement

   d. mission

   e. system objective definition (and required input/output)

   f. mission segment

   g. scenario(s)

   h. functional categories

   i. functional flow and operational event sequences

   j. system specification:

      1. manual

      2. hardwired

      3. automated: Facilitate system functioning
         Override (bypass) system malfunctioning
         Control system graceful degradation
         Permit system to operate.

10. List human factors characteristics that will facilitate successful system development and mission success for each alternative concept (design, development, testing, production, deployment, and operation):

    a. advancement in state-of-the-art human factors technology

    b. currently available human factors technology.

11. List impacts upon cost and system effectiveness for each alternative concept in association with human factors inputs:

    a. R&D, training, personnel, manpower

    b. mission success, vulnerability, survivability.

12. Prepare Human Factors R&D Program Plan tailored to each alternative concept for balance of system life cycle.

Content of the Allocation-of-Functions-to-Man Statement as Part of the Decision Coordinating Paper

A statement of the allocation of functions to man as part of the DCP should include the following considerations:

<u>Assumptions</u>:

- The following items will provide direct input to the specification of the function allocation process:
  - Mission Element Needs Statement (MENS)
  - mission scenarios
  - functional flow block diagrams
  - mission time lines.
- Function allocation will provide support to the proposed system by illuminating the following criteria:
  - system performance
  - cost-effectiveness.

∴ Both criteria have as a function human performance. Human performance can be specified according to degree of detail available about the system mission and environmental factors.

- Function allocation will detail functions involving both operators and maintainers.
- The following general process is assumed for the function allocation process:
  - identify and allocate tasks and functions to be assigned to all personnel
  - identify required equipment
  - evaluate selected man-machine combinations
  - arrange tasks and functions to maximize mission effectiveness and reliability.

Actions:

- This section is arranged according to a topical development sequence for function allocation (not development sequence).
  1. Specify human factors criteria selected for allocation of functions (e.g., response time, error rate or human performance reliability, cost).
  2. Specify other criteria selected for allocation of functions (e.g., cost, personnel cost, required training, weight, development time, development risk, safety, maintainability, system effectiveness, physical volume and size limits, and survivability).
  3. List allocation of each function to:
     a. one or more operators/maintainers
     b. machine only (includes automation)
     c. combination of man and machine
     d. function currently not amenable to man or machine performance.

4. Multiple operator/maintainer and man/machine functions will include specification of the type of redundancy in the task being proposed (e.g., parallel or sequential mode, or hybrid of both).

5. Provide estimate of feasibility of performance for each function allocated. List the effect of different allocation versions upon mission success (e.g., probability). Provide estimate of workload upon operators/maintainers as a result of each allocation version (at least nominally). (At this level of development, workload implies task difficulty and will include requirements for: precision, concentration, criticality, mission priority, and task continuity for operators/maintainers involved in each manned function.) Account for effects of user acceptance for each allocation version.

6. List human performance capabilities required of operators/maintainers for each function involving man and verify whether or not man can perform each in terms of required physical and mental parameters over the required time period and within the anticipated environment.

7. Prepare rank orders for candidate allocation combinations according to criticality of functions. (Criteria for criticality will also be specified.)

8. List all bottlenecks, data overloads, acceptance problems, and other mission-critical faults that occur as a consequence of each allocation version. Specify the means by which each allocation version will relieve them and/or how to modify the allocation version to accommodate them.

9. Prepare a comparison matrix which exhibits all allocation versions versus the selection criteria (entries in the matrix are estimates of absolute performance or rank for each allocation version or each criterion measure).

10. List preferred manned functions as well as other combinations or allocated versions.

11. Provide a rationale for the preferred approach and selection to justify the allocation.

Content of the Task Analysis and Human Engineering Requirements Product

A documented task analysis and statement of the system human engineering requirements shall include the following considerations:

<u>Assumptions</u>:

The following items will serve as input to the process of determining human performance and human factors engineering requirements:

- MENS
- DCP
- Products of function allocation.

Task analytic techniques will be utilized to encompass pertinent aspects of operations and maintenance for a proposed system. Requirements for human factors engineering will also encompass operations and maintenance.

<u>Actions</u>:

1. The principal product of the human task analysis portion of this phase will be a completed task analytic package (including static and dynamic aspects for all tasks). Overall, the package will provide the following data:

    a. tasks and task sequences required of operators and maintainers

    b. actual equipment employed

c. safety

d. maintenance.

Techniques utilized to derive these data will include procedures such as the following: Behavioral Task Analysis, Operability/Maintainability Analysis, Hazard Analysis, Workload Analysis, Task-Equipment Analysis, Operational Sequence Diagrams, and Link Analysis.

2. The overall task analysis, including task descriptions, will be presented in the form of flow diagrams, tabular presentations, and narratives.

3. The human task analysis will commence with a summary of gross tasks. This summary will demonstrate the feasibility of achieving system performance requirements as well as ensuring that human performance requirements do not exceed capabilities. In addition, the effects upon the following items will be described:

   a. manning level

   b. equipment procedures

   c. requisite skills and training

   d. communication requirements (between operators and operators and the system)

   e. logistics support.

4. The human task analysis will specify tasks critical to system performance as well as evidence to support its criticality. These tasks will include but not be limited to the following data:

   a. information requirements by operators/maintainers (including cues for task initiation)

   b. information available to operators/maintainers

   c. evaluation process

d. decisions reached after evaluation

e. action taken

f. body movement required by action taken

g. workspace envelope required by action taken

h. workspace available

i. location and condition of work environment

j. frequency and tolerance of action

k. time base

l. feedback, informing operators/maintainers of the adequacy of action taken

m. tools and equipment required

n. number of personnel, specialties, and experience

o. job aids or references

p. communication required (including type)

q. hazards

r. interaction of multiple personnel

s. operational limits of personnel (performance)

t. operational limits of machine and software.

5. The human task analysis package will provide the results of an operability/maintainability workload analysis (including the interaction of multiple personnel). The operability analysis will detail the following:

   a. design goal--quality of information throughput

   b. predict expected quantity and quality of throughput operators should expect

   c. comparison of predicted with desired throughput and resolution of differences.

The maintainability analysis will detail the following:

a. design goal--including the effects of automated maintence

b. predict performance times for correction (including identification, fault isolation, and correction) of system malfunctions

c. compare predicted maintenance with goal and resolve differences.

6. Develop requirements for human factors engineering by analysis of effects of critical tasks upon system and equipment performance, cost, periods of peak personnel workload, conflict situations placing demands upon personnel and equipment as well as requirements not previously apparent. In addition, life support characteristics will be detailed covering but not limited to the following: noise, shock and vibration, temperature extremes, atmospheric contamination, toxicity, electric shock, mechanical hazards, electromagnetic and nuclear radiation, explosion/fire, pressure and/or decompression.

   This analysis will also result in the prediction of the probabilities for operator and maintainer error. Details to be included in the error analysis are:

   a. identification of the locus of errors

   b. malfunction

   c. extreme conditions and environments

   d. effects of enemy action

   e. recommendations for avoidance of design-induced error

   f. rating of error likelihood

   g. rating of error criticality

h. estimate of seriousness of consequences to personnel and/or equipment; and system, subsystem, and/or component performance.

7. Additional requirements for human factors engineering involved with development of procedural documents, personnel planning, and system testing will be developed. This data will be obtained from an analysis resulting from the compilation of task-related data into preliminary operator/maintainer procedurally oriented task descriptions. (Especially important in this regard would be the determination of system and personnel performance time and accuracy requirements to be used in system test and evaluation. A sequential analysis of the operational sequence diagram would provide these data on a dynamic basis suitable for this use.)

Content of the Optimal Man-Machine Interface Design

The optimal man-machine interface design recommendations should include the following considerations:

Assumptions:

The following items will be regarded as inputs to the human factors engineering design of the man-machine interface:

- Design criteria documents (e.g., MIL-STD-1472)
- Performance specifications
- Drawings and data (e.g., functional flow diagrams, schematic block diagrams, interface control drawings, overall layout drawings)

- Human factors engineering input (e.g., task analysis) converted to detail equipment design features.

The following processes are considered characteristic of this phase of system development:

- Human factors engineering studies, experiments, and laboratory tests (to resolve human factors and life support issues)
- Mockups and models
- Dynamic simulation (necessary for detail design of equipment requiring critical human performance)
- Human factors engineering contributions to detail design
- Human factors engineering contributions to manpower, personnel, and training issues as a consequence of detail design
- Human factors contributions to test and evaluation.

Actions:

1. Effects of the working environment, including habitability and operability, will be presented. These effects will cover the following areas: work environment, crew stations, and facilities. The incorporation of human factors into the detail design of the above will be demonstrated by presenting detail design drawings, specifications, etc. for the following three conditions: normal, unusual, emergency.

Topics to receive coverage will include at least the following:

a. atmospheric conditions

b. weather and climate

c. range of accelerative forces

d. acoustic noise, shock, and vibration

e. disorientation

f. accessibility

g. adequate visual, auditory, and physical links

h. adequate non-workspace areas

i. psychophysical stress

j. fatigue

k. clothing and personal equipment

l. equipment handling

m. chemical, biological, electrical, electromagnetic, toxicological, and radiological effects

n. illumination

o. sustenance, storage, and refuse

p. safety protection.

2. The incorporation of human factors in detail design of the crewstation layout/arrangement and of equipment having an operator/maintainer interface will be demonstrated. This will include the presentation of drawings illustrating the inclusion of human factors; for example: panel layout drawings, communication system drawings, overall layout drawings, and control drawings. The following additional items will be requisite to the demonstration of the inclusion of human factors in system detail design:

   a. ingress and egress to workspace and facilities

   b. a list of panels, racks, controls, displays, and indicators existing at the time of documentation which have received human factors approval

c. rationale of human factors layout/arrangement, detail design of crew station(s), and any equipment having an operator/maintainer interface

d. a list of considerations used to arrive at design decisions: results of studies, requirements based on task analysis, mock-up tests, mock-up based decisions, and simulations

e. a list and explanation for deviations from human factors or design requirements to the man-machine interface

f. sketches, drawings, and photographs of required or anticipated panel rack arrangements or new designs/ design modifications

g. drawings or photographs of each crewstation design showing locations of all crewstation panels in relation seat/operator position.

3. The inclusion of human factors in design considerations involving the interaction of maintenance technicians with their respective equipment will be demonstrated. In general, this will depict the following steps/stages:

   a. recognition of malfunctions (displays)

   b. isolation of malfunctions (troubleshooting)

   c. fault correction (access, removal, and replacement, repair).

A human factors maintainability/accessibility design analysis will be presented to include at least the following:

   a. preliminary drawings, sketches, or photographs showing each equipment and location in relation to surrounding equipment, passageways, and structures (this includes ancillary equipment also)

b. rationale of human factors design of each item requiring maintenance as well as presentation of decisions used to drive the decision process (e.g., MIL-STD-1472, results of studies, simulation, mock-ups)

c. incorporation of maintenance task analysis

d. descriptions to include but not be limited to the following:

- physical size, purpose of support, and test equipment required for maintenance
- maintenance procedures
- relation between accessibility and failure rate, service frequency, calibration frequency, and requirements for rapid maintenance
- methods used to determine accessibility for maintenance
- anticipated maintenance and accessibility problem areas.

4. Best available data on equipment operating procedures, operational sequence diagrams, and task analysis will be provided to organizations responsible for manpower development.

5. A human factors test and evaluation plan will be prepared to cover the following general concepts:

a. fulfillment of human factors requirements

b. conformance to human factors design criteria

c. quantitative measures of system performance

d. detection of undesirable design or procedural features.

APPENDIX D

IMPACT ANALYSIS STEPS

APPENDIX D
IMPACT ANALYSIS STEPS

Human Factors Impact Assessment:
Conceptual Framework

Basic Framework and Steps

Exhibit D-1 outlines the basic impact assessment framework. The development and presentation of the analysis entails ten steps or phases. The steps are presented in a logical sequence, in three groups; but in any one analysis, as indicated by the dotted lines, it may be necessary to repeat several steps in different sequences to refine perceptions and assessments of critical issues. Each step will be discussed in some detail below.

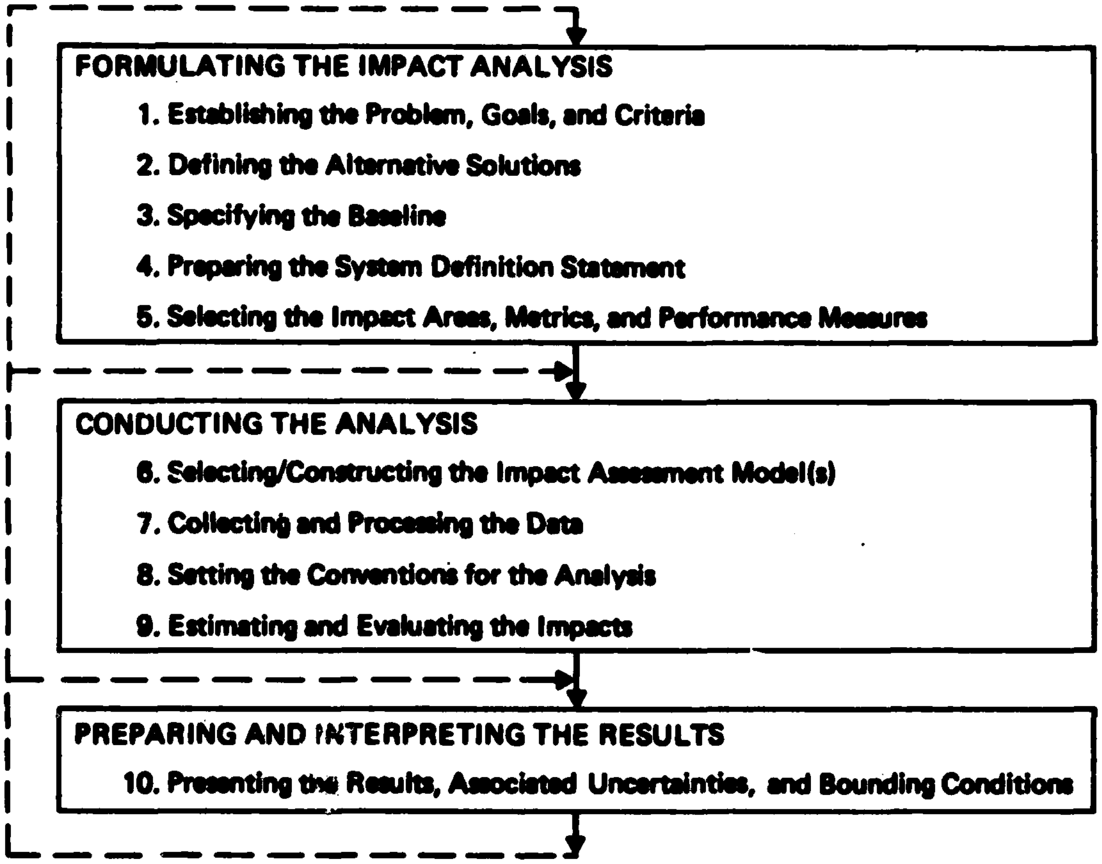
1. Establishing the Problem, Goals, and Criteria. The objective of this step is to isolate the specific issues to be analyzed, to bound the requirements, to specify the specific goals and objectives, and to derive the decision criteria.* Fisher (1971), Quade (1975), and Goeller (1976) provide useful, generic guidance for this step. Specifically, this step defines the content and purpose of the human factors product to be developed. The principal human factors products are listed in Chapter 2.

This step is one that should be recognized as a variation on the generic system analysis method. The rule is: look at the ends first and work back from those ends. In human factors terminology, we would probably prefer the sequence: Goals, Objectives, and Outcome Measures (or, for the latter, Dependent Variables). However, the principle of going from the broad to the narrow and the idea of a hierarchy that includes more

*In this discussion, the term goal represents an "end," objective a "means" (that is, a specific accomplishment within an explicit time or cost target), and criteria represent specific decision conditions.

Exhibit D-1

Impact Assessment Framework



"variables" as that move is made is a common link. This arrangement is illustrated in Exhibit D-2 in a particular cost-benefit impact assessment convention (Goeller, 1976; Ostrofsky, 1977).

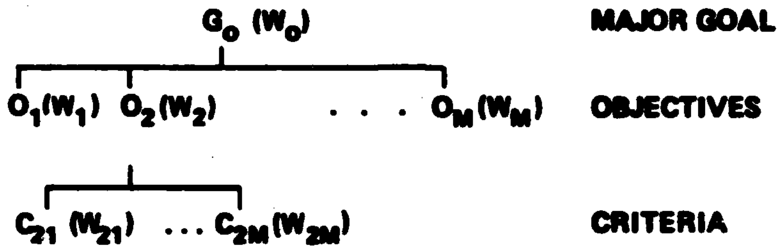
The following hypothetical example illustrates the use of goals, objectives, and weights. Assume that the system under consideration is proposed for the XYZ main battle tank. The major goal is to achieve an armored fighting unit that could defeat its hostile counterpart in certain tactical scenarios. The objective, O_1, could be that the frontal armor would hold against 80% of main round hits (i.e., any grazing angle greater than $\pm 5^{\circ}$). The objective, O_2, could be to achieve an average first-round time advantage of 3 seconds. In this case, O_2 could receive an a priori value weight somewhat higher than O_1.

Criterion C_{21} (contributing to objective O_2) could be a maximum turret traverse rate of $=> 20^{\circ}$ per second. Criterion C_{22} could be a maximum elevation/depression rate of $=> 45^{\circ}$ a second. In this case the criteria might be assigned equivalent value weights.

Several attributes of the hierarchical setup should now be clearer. Specifically, as one moves down the structure, the objective measurability improves. But more importantly, the actual assumptions about performance are made very explicit. That is, the design assumption clearly is that <u>if</u> a given elevation/depression rate <u>and</u> a given traverse rate are achieved, a given first round time advantage will result. Not only is that assumption measurable (e.g., by computer simulation), but the tentative weight assignment is also similarly measurable. Computer simulation would permit a whole range of permutations on the traverse rates and elevation/depression rates to be explored,

Exhibit D-2

Goal Relevance Tree Hierarchy of Goals - Objectives - Criteria



RELATIVE WEIGHTS:

TOTAL VALUE = W_O
OBJECTIVE WORTH = W_i
CRITERIA WORTH = W_{ij}

and a very close approximation of the relative importance of one to the other could be obtained. Moreover, the weights could be revised as other kinds of testing were done.

A notable gap in the above synthetic scenario is the lack of explicit consideration of the human factors aspects of sighting and firing the main armament. For example, human factors questions would arise about the compatibility of a maximum 80° traverse rate with the human factors requirement (hypothetical) to lock-on to a target on the first traverse with no waver. Human factors engineering solutions based on traverse deceleration rate damping, sight reticule size, etc., would need to be fitted into the goal and objective-attainment relationship as constraints. The basic message here is that it might not pay to have a relatively high traverse rate, if it led to an overswing of the turret 9 times out of 10 because the rate/velocity dynamics were incompatible with normal human (psychomotor) tracking capabilities.

The characteristics of the appropriate set of goals, objectives, and criteria is critical to the effectiveness of the analysis. Several useful discussions on this process are provided by Fisher (1971), Quade (1975), and Ostrofsky (1977). The input-output matrix technique used by Ostrofsky (1977) appears to be a particularly useful way to structure this step. An illustration of the matrix is shown in Exhibit D-3. The row headings define the user and the system major phases, and the column headings define the requirements and bounding or constraining conditions (e.g., resources). Other row headings, such as those employed by Ostrofsky, could be used in this same format to formally incorporate human factors considerations into the system design process.

Exhibit D-3

Input-Output Matrix for Problem Formulation

Major System Development Phases	Inputs		Outputs	
	Intended	Environmental	Desired	Undesired
Mission Analysis				
Concept Development				
Demonstrations and Validation				
Full-Scale Development				
Production				

(Source: Ostrofsky, 1977)

The output from this step is a problem statement, an input-output matrix for bounding the design-analysis problem, and a set of weighted objectives and decision criteria to be used. The problem statement is an issue that one or more human factors related actions can help to resolve.

2. Defining the Alternative Solutions. The objective of this step is to generate a set of explicit strategies or alternative solutions to resolve the problem or issue identified in Step 1. For example, within the human factors principal R&D product--development of the role of man as a part of the mission--alternative crew sizes, mission flexibility, and system recoverability could be specific considerations. There are two major ways this can be done. The first is to specify a set of alternative design configurations/characteristics or process changes at the subsystem, component, or function level. The second is to specify a criterion function (see Ostrofsky, 1977) that incorporates the design parameters in a mathematical function, and to exercise the function to determine the preferred design or system specification. Either approach can be used. The former is more common and straightforward. The latter is typically more rigorous and requires more definitive analysis.

Making the decision options explicit is a fundamental principle of systems analysis. We can illustrate this principle in the context of using cost-benefit impact analysis to measure the impact of human factors.

Methodologies such as cost-benefit analysis are being used increasingly to support system design decisions and, to a lesser degree, to support the management decisions in system development. The application illustrated here includes both types, but emphasizes the latter. Management decisions of special interest are

those concerning when particular inputs to the design deliberations should be encouraged, and how much investment to make in each potential source of such inputs.

For illustrative purposes, then, let us say that the range of options available to the Project Manager with respect to when to encourage human factors inputs is given an initial framework by the four design phases previously defined, i.e.:

- Mission Analysis (MA)
- Concept Development (CD)
- System Demonstration/Validation (SD)
- Full-Scale Development (ED).

The main options, then, are:

1. None
2. MA only
3. CD only
4. SD only
5. ED only
6. MA and CD
7. MA and SD

   •

   •

   •

16. MA and CD and SD and ED (all).

(In the higher-order options, the question of relative degree of input becomes a factor--but that factor overlaps with the allocation issue and adds a complication that is not needed for this illustration.) Thus, in this illustration there are 16 distinct alternatives for when human factors inputs can be encouraged. It is sufficient for this step simply to enumerate them.

3. Specifying the Baseline. The objective of this step is to define the status quo conditions relevant to the analysis; namely, the baseline. Projected impacts are evaluated in terms relative to a baseline. For each system development phase, a systems baseline must be defined. Thus, if a human factors action resulted in a design change in the demonstration/validation phase, the baseline for the succeeding system development phase would incorporate that change because it had already been accomplished. Thus, the baseline is generally tied to a phase in the development cycle.

The baseline provides a basis for the projection of future conditions in which the human factor changes under consideration are not developed and implemented. A baseline could be defined for a set of human factor impacts when the individual impacts cannot be isolated. However, it must always be defined so that the impact areas and metrics under consideration are explicitly identified.

The easiest way to understand this step is to make the argument: each new system has a (more or less direct) precursor system (or systems). The baseline rests on the precursor or composite family of precursors which we can call the reference system. In most instances, the reference system will be the one that would be used to perform the mission if the new system were not developed. For those analyses in which human factors are emphasized, the mission compatibility criterion has a strong old-new functional similarity aspect.

The following discussion illustrates the notion of the mission/functional analysis in defining the baseline. There are two analytic substeps in establishing the baseline for system design and cost projection purposes: Functional Differences and

Functional Deficiencies. The first entails the specification of the reference system similar functions and any technological differences between the reference system and the proposed new system. For example, for the XYZ tank, the reference system would be the operational MYY tank, and the technology differences that impact on the man-machine functions could include those in the main armament, armor metallurgy, turret stabilization, fire control, and propulsion components. The functions of interest are those needed to operate and maintain these components. The product from this substep is a reasonably detailed <u>functional</u> differentiation.

The second substep is a deficiency analysis of the reference system. Again, it is functional deficiencies that count. For example, was/is the reference system deficient in maneuverability? In what specific ways? We also need to know what specific human factors related deficiencies were brought to light during the field use of the reference system. Possible source data for this kind of deficiency identification could include the complaints of operators and maintenance personnel. Observations of the actual behavior of crews and maintenance units in action could be appropriate. The human factors specialist could go through dry runs of crucial segments of operational and/or maintenance sequences. The product from this substep is a definitive list of deficiencies. If value weights could be assigned to each deficiency in an unambiguous manner, this could also be useful.

The baseline is completed as a step in the overall methodology when the array of technological changes and reference system deficiencies are put together in such a way as to give a preliminary picture of the prospect of whether the technological changes will tend to ameliorate or accentuate the deficiencies on

a one-by-one basis. Thus from the baseline we can get a set of assumptions that indicates what some of the major design problems are going to be for the new system and, importantly, which are likely to be human factors related.

4. Preparing the System Definition Statement. The objective of the system definition statement is to summarize concisely all the essential information and assumptions about the subject system that are necessary to conduct the impact assessment. An important part of this definition is a historical record of the evolution of the system's design and development, and the corresponding impact and cost estimates. Though it will not be possible in many instances to aggregate cost-benefit/impacts from system development stage to stage, the definition statement can provide selective evidence of the role and contribution of human factors R&D.

At a minimum, the system definition statement should contain specifics on the following:

- Mission Profile (What is the system for?)
- System Performance and Operational Characteristics (What are the system capabilities?)
- Acquisition Program Schedule (How is the system to be procured?)
- Deployment (Peacetime and Wartime) Plan (How will the system be utilized?)
- Support Concept (Initial and Mature) (How will the system be supported and maintained?)
- Logistics Goals (What are the unique logistics related goals, e.g., reliability?)

- Integrated Logistics and Training Considerations (How will the operators and maintenance personnel be trained? How will the required material be purchased, managed, etc.?)
- Human Factors Related Issues (What operation and maintenance considerations can affect the cost, capability, and compatibility of the design?)

The first seven items are typically called for under current, recommended major weapon system acquisition analysis guidelines.* For these analyses, we have augmented those guidelines by adding a separate discussion of human factors related issues that should be considered. These are issues that would be noted and discussed in the human factors products (e.g., role of man) at the different system development phases. The outcome of that consideration and/or impact assessment should be reviewed throughout the system development stages.

5. Selecting the Impact Areas, Metrics, and Empirical Measures. The objective of this step is to define the system's life cycle cost, capability, and compatibility impacts, metrics, and empirical measures for the goals and criteria identified in Step 1. Some criteria may be included explicitly as cost or empirical metrics, depending on their specificity, measurability, and abstract properties.

Metrics and measures used to define the specific nature and focus of the human factors R&D impact must be tailored to the phase of system development, the human factors product form,

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*See, for example, DOD Directive 5000.1, Major System Acquisition; 5000.39, Acquisition and Management of Integrated Logistics Support for Systems and Equipment; and DOD Instruction 5000.2, Major System Acquisition Process.

and the system-mission characterization. The impact area(s) and associated component metrics and empirical measures comprise the vocabulary to describe the effect of the human factors related change(s).

The three generic impact areas--cost, capability, and compatibility--were introduced in the Phase I report. In Exhibit 3-2, each of the impact areas is shown to be definable in terms of a number of metrics, and the metrics were shown to be functions of combinations of empirical measures. The generic hierarchical relationship also is illustrated in that exhibit. Moreover, the measures and metrics for capability and compatibility, in particular, reflect contemporary usage for describing cause-effect relationships in both human factors R&D and system engineering. In general, a human factors related change that affects capability or compatibility will also affect cost.

The set of vocabulary terms presented in Chapter 5 are from our preliminary findings. They represent an initial step toward the definition of a formal and stable set of terms to discuss, model, and communicate the effects of human factors related changes in military systems design and development. Each of the impact areas and their component metrics and measures are discussed briefly below.

- *Cost:* For a weapon system specific setting, the cost impact area is the life cycle cost of the system. An example of cost metrics would be operations and support while a related measure, for example, would be Below Depot Maintenance. If a military system, other than a weapon such as a C^3I system, was the subject of the analysis, it is likely that some different cost measures

would be required. The guiding criterion is: select the set of cost metrics and measures that reflects the significant, relevant costs effected by the human factors related changes.

- *Capability:* For a weapon system specific setting, the capability impact area is the mission worth of the system. A preliminary, empirically derived set of capability metrics (e.g., availability, reliability) and measures (e.g., mean-time-to-repair, mean-time-to-failure) were derived during Phase I. The particular combination of measures used to functionally define a metric is dependent upon the system or process being analyzed, and the various ways the effect of the human factors changes can be measured.

- *Compatibility:* For a weapon system specific setting, the compatibility impact area is the physiological and psychological suitability of the design. A background discussion of compatibility metrics (e.g., user acceptance, motivation) and measures (e.g., temperature, noise, vibration stress, altitude) is given in Chapter 5. The underlying notion of the compatibility impact area is that many human factor related effects are not easily assessed using the same quantitative metrics and measures as for cost or capability. For example, reducing an operator's stress is a substantive benefit, even though its contribution to enhanced system performance is not directly quantifiable.

The result of this step is a specific set of vocabulary terms to be used for describing the impacts, and in selecting/constructing a model to estimate the values for the measures, metrics, and ultimately their effects on the impact areas.

6. Selecting/Constructing the Impact Assessment Models. The objective of this step is to derive or select appropriate techniques or models that can provide both quantitative and qualitative measures of the cost, capability, and compatibility impacts expected from the application of the human factors change.

In effect, one needs to relate the criteria from Step 1, the information from Steps 2 to 4, and the impacts and metrics from Step 5. Furthermore, that relationship must be relevant to human factors R&D products and the system development process. These relationships are tailored to and essentially define the content of the human factors efforts discussed at length in Chapter 2.

A reasonable approach is to utilize Ostrofsky's (1977) design methodology as a basic procedure, and to augment it with other models that deal explicitly with life cycle cost and system capability measures. (Examples of the latter are Goclowski, 1978; Forster, 1974; Fabbro & Fiorello, 1977; AF-Logistics Support Cost Model, Design-to-Cost Model, and the Mission Success Completion Probability Model.) In addition, there are several techniques, other than Ostrofsky's, for evaluating and quantifying (imposing cardinal measures) on essentially qualitative, ordinal measures. Examples are Gardiner (1979), Saaty (1979), Quade (1975), Hays (1975), Dalky (1969), and Linstone (1975).

Briefly, the sequence envisaged is as follows (Ostrofsky, 1977):

a. For the criteria defined in Step 1, specify the underlying parameters. These parameters represent the constituents of the criteria in a systems-component sense. Each parameter is classified in terms of being:

- measured directly
- measured from a model
- included in other elements
- not measurable within existing resources.

b. Define submodels of the primitive, measurable elements to define functionally the higher-level parameters.

c. Combine the submodels into an overall model to estimate each criterion, and, in turn, an aggregate criteria function for the overall goal.

While each of these steps is critical, it is most important to understand the causal linkage between the elements, which can be a mixture of qualitative and quantitative measures, the parameter submodels, and, in turn, the criterion function. For a "hard" parameter such as reliability, the linkage between it and cost and availability is rather well understood, and many acceptable models exist. For the "soft" parameters such as user acceptance, the linkage is not nearly so clear. What is required is a procedure that will handle both quantitative and qualitative criteria (and their parameters and elements) in a systematic and credible manner.

In summary, Step 6 puts all the information from Steps 1 to 5 into a formal setting with functional, causal relationships. From the previous steps, we have:

(Step 1)

- A set of goals, objectives, and criteria in a hierarchical array.

(Step 2)

- A listing of (management) decision options.

(Step 3)

- A specification of the baseline in the form of an explicit comparison between the reference system and the proposed new system with respect to technological differences and functional deficiencies in the reference system, and projected implications of such deficiencies.

(Step 4)

- An overall characterization of the proposed new system and how it is to be operated and maintained.

(Step 5)

- A listing of critical metrics and empirical measures.

The model used to put these elements together can take a number of different forms, depending upon the system development phase and problem setting. A discussion of model types and selection criteria is given in the last section of this chapter. We can now proceed to summarize the final four steps.

<u>7. Collecting and Processing the Data</u>. Given the specification of the impact areas, metrics, and the model form, this step provides the required data to "drive" the model. Frequently, the lack of data in sufficient quantity or detail will constrain the nature and accuracy of the cost-benefit analysis.

8. Setting the Conventions for the Analysis. This step specifies the conventions or ground rules used in arriving at the cost, capability, and compatibility impact estimates. Conventions for cost and capability analysis should cover:

a. Normative projections

b. Constant versus adjusted dollar cost estimates/ projections

c. Mature versus transient system characteristics

d. Personnel budget or economic costs

e. Capital investment leadtime considerations

f. Relevant, variable versus total costs

g. Uncertainty analysis (including technical risk)

h. Presentation and documentation standards.

9. Estimating and Evaluating the Cost Benefits. This step provides the output from the model and data prepared in Steps 7 and 8.

10. Presenting and Interpreting the Results. This step entails preparing the presentation (including illustrations and documentation of the results), identifying the requirements for additional analysis, and specifying important issues that have high degrees of uncertainty. An important part of the presentation is a description and quantitative portrayal of how the change impacted the system design and its life cycle costs and performance. Where feasible, the specific contribution of the human factors change should be isolated. Often it may not be possible to isolate the impact. In those instances, it may only be reasonable to make the comparisons at the aggregate or systems level (e.g., new vs. baseline), and to infer the role of the human factors impact. In addition to the standard tabular and

graphic presentation, the notion of color scoreboards, as used by Goeller (1976) can be used to make and present comparisons of alternatives.

APPENDIX E

PRELIMINARY LIST OF METRICS

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System-Related Terms and Associated Dimensions (Unit of Measure)

ACCESSIBILITY	subjective: satisfactory/unsatisfactory ease of admission to various areas of an item
ACCURACY	probability/frequency of documented error
CAPABILITY	subjective: mission objective achievable given the condition during the mission
COMPATIBILITY	subjective: ability of items of equipment to coexist (including effects of temperature and moisture
CRITICALITY	subjective: relative degree of task importance for mission success
DURABILITY	probability: item will survive a) its projected life b) overhaul point c) rebuild point without a durability failure (failure that causes an item to be rebuilt or replaced)
EASE OF USE	subjective: tasks associated with simplicity, readability, etc.
FAILURE RATE/FREQUENCY	1) number of failed items 2) number of effects (out of tolerances) per month, week, hour, etc.
FIRING RATE	time (measured from firing to reloading of weapon)
HABITABILITY	subjective: adequacy/ease of space, transport, watch standing, rest, relaxation, workspace and access
MALFUNCTION, SYSTEM INITIATED	frequency per unit time (hours) based on available reliability data & maintenance data
MEAN FLIGHT HOURS BETWEEN MAINTENANCE ACTION	mean probable flight hours between maintenance actions
MEAN-MAINTENANCE TIME	1) mean hours preventive and corrective maintenance 2) total preventive and corrective maintenance time divided by total number of preventive and corrective actions during a specified interval
(MTBAMA) MEAN TIME BETWEEN ANY MAINTENANCE ACTION	same as MTBF except all maintenance actions are collected as data

(MTBF) MEAN TIME BETWEEN FAILURE	1) mean time a system functions until occurrence of a failure requires corrective maintenance (characteristically over a two-month period) 2) total functioning life of a population of items divided by the total number of failures within the population during a measurements cycle (time, cycles, miles, events, etc.)
(MTBM) MEAN TIME BETWEEN MAINTENANCE	mean of the distribution of time intervals between maintenance actions
(MTBUMA) MEAN TIME BETWEEN UNSCHEDULED MAINTENANCE ACTION	same as above except only unscheduled maintenance is collected as data
(MTTR) MEAN TIME TO REPAIR	total corrective maintenance time divided by total number of corrective maintenance actions during a specified interval
($MTTR_A$) MEAN TIME TO REPAIR (ACTUALLY ACHIEVED)	total corrective and preventive maintenance time divided by total number of corrective and preventive maintenance actions during a specified interval
($MTTR_F$) MEAN TIME TO REPAIR (FLIGHTLINE)	mean probable time spent in flightline maintenance before system is returned to a ready-for-operation condition
($MTTR_I$) MEAN TIME TO REPAIR (INHERENT)	total corrective maintenance time divided by total number of corrective maintenance actions during a specified interval
($MTTR_O$) MEAN TIME TO REPAIR (OPERATIONAL)	total corrective maintenance time divided by total number of corrective, preventive, administrative, and support maintenance actions during a specified interval
(OPERATIONAL) SUITABILITY	subjective: 1) establishment of system operability in operational environment (within stated constraints) 2) identification of adequate instrumentation, comfort, visibility, handling, etc. of systems by personnel
(PILOT) WORKLOAD	subjective: *degree of effort required to accomplish a specific task*
PRODUCIBILITY	(T&E application): subjective ability of differences between prototype and production models to achieve desirable result (as a result of ECP & program change orders)
READY RATE, OPERATIONAL	% of assigned items capable of performing an assigned mission or function

SAFETY	1) probability of injury or damage 2) subjective: satisfactory/unsatisfactory materials, fire & explosion protection, mechanical & electrical hazards)
SERVICEABILITY	time: ability to service in specified interval
STANDARDIZATION/ COMMONALITY OF DESIGN	degree of similarity (lack of ambiguities) of two displays designed to same specifications and standards
SUBSYSTEM EFFECTIVENESS	subjective: the technical capability of a sub-system (RADAR, FLIR, etc...) to accomplish a specific task
SURVIVABILITY	probability that a system will withstand hostile man-made environment and retain mission accomplishment capability
TIME, DOWN (DOWN TIME)	time (hours, frequency, duration) which an item is not in condition to perform its specified function
TRANSPORTABILITY	subjective: ease of transit, packaging, load/ unloading, security & fastening
WEAROUT	rate of increase in failure rate of items over system life (cycles, time, miles)

Personnel-Related Terms and Associated Dimensions (Unit of Measure)

ACCIDENT RATE	number per specified number of hours
ACCURACY	1) kill/no kill ratio 2) % correct 3) subjective: associated with cognitive skills (e.g., observing, estimating, detecting, recognizing, positioning, reading, etc...) 4) measure of precision and/or timeliness of performance
ANXIETY	subjective: stress factors associated with pilots (e.g., training, confidence)
APTITUDE AND SKILL	1) testing scores (e.g., AFQT) 2) subjective: low vs. high
ATTRITION/TURNOVER	% attrition—number of attrited personnel divided by number of attrited personnel plus number of non-attrited personnel
DISSATISFACTIONS/ SATISFACTIONS	subjective: ratings of challenge, personnel-job match, perceived degree of utilization
EFFICIENCY	rating success on a task
ERROR RATE (ANALYSIS)	1) mean error per performance time 2) percent and/or number of operator error (e.g., forgetting, accidents, inability, etc...) 3) analysis: includes a) amplitude b) frequency c) type d) change over time
ILLUMINATION LEVEL	1) measure: luminance 2) subjective: number of lighting deficiencies
INJURY	subjective: injury type, severity, frequency
MAINTENANCE CORRECTIVE	number, rate, frequency of acts performed to restore an item to a specified condition
MAINTENANCE, PREVENTIVE	number, rate, frequency of actions performed to retain an item in a specified condition
MALFUNCTION, HUMAN INITIATED	frequency of test participant (operator) error resulting in system/item malfunction
(MOBA) MILITARY OPERATIONS IN BUILT-UP AREAS	1) communications distance (limitations) 2) weapons effectiveness 3) tactics effectiveness

MORALE	subjective: ratings of individual personnel identification and satisfaction with work group, job activities, duties, supervision, etc.
MOTIVATION	subjective: rating of desire to perform duties, obtain experience, advance
NIGHT OPERATIONS	performance (target identification) in night missions
NOISE/BLAST	sound pressure measurements (e.g., dbs, amplitude, also velocity, wavelength frequency in herz)
PERFORMANCE TIME OR RATE	mean time/number per some unit/rate
PRODUCTIVITY	units produced per some interval
PROFICIENCY	test scores (written)
RADIATION	radiation effects aircrew performance on radiation environments
REACTION TIME	1) (time reaction): uptime to initiate a mission, measured from the time the command is received 2) operator perception time (or start time) in response to some initiating stimulus
STRENGTH	amount lifted (kilograms)
STRESS, GENERAL	gas (general adaptation syndrome)
STRESS, TASK OVERLOAD	subjective: workload excessiveness
TASK COMPLEXITY/ DIFFICULTY	subjective: rating based on knowledge and skill required for performance
TASK DURATION	total time required for task completion (also as in tracking targets-% of time on target)
TASK FREQUENCY	number of responses made by an operator(s) in a specified interval
TEMPERATURE	measures of comfort and performance in variable temperatures
TIME, ADJUSTMENT/ CALIBRATION	time required to make needed response
TIME, CHECKOUT	time required to verify performance of an item (in specified condition)
TIME, FAULT CORRECTION	time required to correct a failure
TIME, FAULT (ISOLATION) LOCATION	time (hours) measured from discovery of a fault/ failure to correct identification of failed item

TIME, TASK TIME	time required to perform task
TIME, TURNAROUND	time required to service or check out an item for recommitment
USER ACCEPTANCE	subjective: underuse, misuse, abuse of equipment due to dissatisfaction with: a) machine function b) status c) economic fears d) survival fears e) enjoyment of manual performance of tasks
VAPORS/EMISSIONS	measured in parts per million (PPM) over specified time
VIBRATION	frequency (in Hz) over a unit exposure time
WINDFORCE (Q-FORCE)	windspeed indicator (impact on physical operating environment)
WORKLOAD	subjective level of effort required to accomplish a task